EXPLORING THE RELATIONSHIP BETWEEN COLLEGE STUDENTS' UNDERSTANDING OF PARTICLE THEORY OF MATTER AND THEIR CONCEPTUAL UNDERSTANDING OF VAPOR PRESSURE

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Submitted to the Institute for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Master of Science

Graduate Program in Secondary School Science and Mathematics Education
Boğaziçi University
2019

ACKNOWLEDGEMENTS

First of all I would like to thank my thesis advisor Assoc. Prof. Emine Adadan who supported me with her precious knowledge, experience and kindness. She made a great contribution with her guidance and persistent help.

I would also like to thank my thesis committee members, Assoc. Prof. Funda Savaşcı Açıkalın and Assist. Prof. Sevda Yerdelen Damar for their time and comments. They helped me to improve this study with their valuable feedbacks.

I am grateful to my friends and colleagues who encouraged me during this journey.

My biggest thanks are for my parents, Hülya and Mehmet, and also for my dear brother, Serhat. They have always been trusted me with their endless love and precious support. I am very lucky to have such a perfect family.

ABSTRACT

EXPLORING THE RELATIONSHIP BETWEEN COLLEGE STUDENTS' UNDERSTANDING OF PARTICLE THEORY OF MATTER AND THEIR CONCEPTUAL UNDERSTANDING OF VAPOR PRESSURE

This mixed method study mainly explores the association between first-year college students' understanding of particulate nature of matter (PNM) and their understanding of vapor pressure. The goal was to identify and describe the levels of understanding of specific vapor pressure concepts of a group of participants with a high understanding of PNM and a group with a low understanding of PNM. The sample of this study was 48 first-year college students who were enrolled in General Chemistry I course. Data were collected through a diagnostic test about the PNM and interviews on vapor pressure. Data obtained from diagnostic tests and interviews were coded and analyzed by using qualitative and quantitative methods. Different aspects of vapor pressure were evaluated by giving numeric points to each participant's responses in the quantitative analysis. Each participant's level of conceptual understanding about specific vapor pressure concepts was identified in the qualitative analysis. According to data analysis results, it was concluded that there was a statistically significant difference between the groups of high understanding of PNM and low understanding of PNM in terms of their understanding of vapor pressure. Participants with a high understanding of PNM were more likely to develop a scientific understanding in vapor pressure.

ÖZET

ÜNİVERSİTE ÖĞRENCİLERİNİN MADDENİN TANECİKLİ YAPISI VE BUHAR BASINCI HAKKINDA KAVRAMSAL ANLAMALARI ARASINDAKİ İLİŞKİNİN İNCELENMESİ

Bu karma yöntem çalışması, üniversite birinci sınıf öğrencilerinin maddenin tanecikli yapısını anlama düzeylerinin buhar basıncını anlamalarına etkisini incelemektedir. Çalışmanın amacı katılımcıların maddenin tanecikli yapısını anlama düzeyine göre buhar basıncına ilişkin belirli kavramları anlama düzeylerinin değişip, değişmediğini belirlemektir. Çalışmaya Genel Kimya I dersine kayıtlı 48 üniversite birinci sınıf öğrencisi katılmıştır. Veriler maddenin tanecikli yapısına ilişkin bir değerlendirme testi ve buhar basıncı konusuna ilişkin yapılan birebir görüşmelerle toplanmıştır. Değerlendirme testi ve birebir görüşmelerden elde edilen veriler kodlanmış; nicel ve nitel olarak analiz edilmiştir. Nicel analizde her bir katılımcının belirli buhar basıncı kavramları hakkında açıklamalarına sayısal puanlar verilmiştir. Nitel analizde ise her bir katılımcının belirli buhar basıncı kavramlarını anlama düzeyleri belirlenmiştir. Çalışmadan elde edilen verilerin analizi sonucunda, maddenin tanecikli yapısına ilişkin ileri düzeyde anlama geliştirmiş katılımcılar ile maddenin tanecikli yapısına ilişkin zayıf düzeyde anlamaya sahip katılımcılar arasında istatistiksel olarak fark olduğu saptanmıştır. Maddenin tanecikli yapısına ilişkin ileri anlama düzeyine sahip katılımcıların buhar basıncı konusuna ilişkin de bilimsel olarak kabul gören kavramsal anlamalar geliştirdikleri tespit edilmiştir.

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N	Number of participants
p	Significance level
Sk_2	Pearson's coefficient of skewness
U	Mann-Whitney U value

LIST OF ACRONYMS / ABBREVIATIONS

AC	Alternative Conception
NU	No Understanding
P nH	nth Participant in High PNM Group
P nL	nth Participant in Low PNM Group
PNM	Particulate Nature of Matter
PNM-DI	Particulate Nature of Matter - Diagnostic Instrument
PU	Partial Understanding
PU/AC	Partial Understanding with Alternative Conception
SU	Scientific Understanding

1. INTRODUCTION

The study of chemistry involves observing and explaining the state of matter in its various forms. However, many concepts in chemistry are abstract; observing and explaining of chemical phenomena are studied in terms of atoms and molecules. In view of this, understanding the nature of matter is a critical issue for chemistry students.

According to Piagetian theory, students who possess the ability to logically operate on information and symbols must be in the formal operational stage. To understand abstract concepts such as atoms and molecules, students need concrete experiences (Nurrenbern, 2001). Chemistry education studies have argued that more than 50% of first-year college students may be in the transition stage between the concrete and formal operational stage (Abraham *et al.*, 1994; Goodstein and Howe, 1978; Herron, 1975; Moore, 2012). For this reason, students have difficulty in understanding and explaining chemical phenomena at the particulate level that cannot be observed directly (Cole and Todd, 2003; Pınarbası and Canpolat, 2003).

Different representations have been developed to achieve conceptual understanding by connecting concrete and abstract concepts so that students can understand chemical concepts (Johnstone, 1991). These macroscopic, microscopic and symbolic representations are determined to be important for improving conceptual understanding of chemical concepts. When students fail to understand this threefold relationship, they develop many alternative conceptions related to concepts they do not grasp totally in submicroscopic level (Strauss, 1996).

Because of the abstract nature of atoms and molecules, the particulate theory of matter is a difficult subject, which requires students' ability to enhance beyond concrete cases in real world (Bodner, 1991; Freasier *et al.*, 2003; Gabel, 1993). Researchers have argued that particulate nature of matter refers to atomic, molecular, and ionic interactions that lead to observable chemical phenomenon (Gabel, 1999; Johnstone, 1991). The importance of the particulate nature of matter is clearly defined as it is relationships between structure, properties and applications of materials, which will in turn help us understand phenomenon in the world around us (Margel *et al.*, 2008).

The particulate theory of matter is a core concept in chemistry education, on which many advanced concepts are based (Williamson and Abraham, 1995). Chemical concepts such as bonding, chemical reactions, phase change and vapor pressure are related to particulate theory of matter. However, the results of diagnostic tests show that students do not easily understand the particulate nature of matter (Othman *et al.*, 2008). Furthermore, students who hold alternative conceptions associated with particulate nature of matter; tend to develop alternative conceptions of more advanced concepts such as vapor pressure related to particulate nature of matter.

Vapor pressure is one of the concepts related to particulate nature of matter. Understanding vapor pressure and its associated concepts is prerequisite to understand many concepts such as colligative properties phase change, evaporation and boiling. Many research show that students have difficulties in understanding the concept of vapor pressure and they develop alternative conceptions of vapor pressure and its associated concepts easily (Azizoglu *et al.*, 2006; Canpolat *et al.*, 2006; Gopal *et al.*, 2004). There are many studies on students' alternative conceptions about particulate nature of matter and vapor pressure; however, there appears to be a lack of studies that investigate the correlation between these two concepts. The current study has the potential to fill the deficiency in this area.

1.1. Purpose of the Study

The purpose of this study is to examine the association between first-year college students' understanding of particulate nature of matter (PNM) and their understanding of vapor pressure. In doing so, the study first identifies the participants' understanding of PNM and vapor pressure, and then look at how the participants' level of understanding of PNM associate with their understanding of vapor pressure. It is expected that the results and implications derived from this study will provide useful knowledge for teaching of these fundamental chemistry concepts.

1.2. Research Questions

The current study attempts to answer the following research questions:

- How do the groups of first-year college students with a high understanding of the PNM and a low understanding of PNM compare in terms of their understanding of vapor pressure?
- What level of conceptual understanding of specific vapor pressure concepts are demonstrated by the groups of first-year college students with a high understanding of the PNM and a low understanding of PNM?

1.3. Significance of the Study

Many concepts studied in chemistry are abstract so it is argued that alternative conceptions play an important role in learning chemistry (Mulford and Robinson, 2002) because students' pre-existing ideas contradict to accept new information. This idea is consistent with theories which argue that students build cognitive structures of phenomenon and will ignore or reject any information that cannot be connected and integrated into this existing cognitive structure (Osborne and Wittrock, 1985).

Many learning problems in chemistry lie in understanding the relation between the molecular and submicroscopic representations because students basically transfer properties of the bulk matter to the particle that form the matter (Taber, 2001). For this reason, many students do not develop an understanding of the particulate theory of matter by the time they have completed the topic (Krnel *et al.*, 1998).

Research studies indicated the importance of particulate nature of matter to learn chemistry meaningfully with deep understanding. The particulate nature of matter lays the foundation for understanding of other science concepts such as bonding, chemical reactions, phase change and vapor pressure. The diagnostic tests inform that students do not easily understand the concepts related to particulate nature of matter (Othman *et al.*, 2008). In addition to studies about particulate nature of matter, there are some research about possible associations between students' understandings of the particulate nature of matter and the other concepts in chemistry.

There are many studies on students' alternative conceptions about particulate nature of matter and vapor pressure (Ben-Zvi *et al.*, 1986; Griffiths and Preston, 1992; Pinarbasi and Canpolat, 2003); however, there appears to be a lack of studies that analyzing the correlation between particulate nature of matter and vapor pressure (Tumay, 2014). This study differs from the others in terms of investigating the relationship between students' understanding of particulate nature of matter and vapor pressure concepts.

2. LITERATURE REVIEW

This chapter reviews the related literature informed the current study including four main sections namely constructivist view of learning, conceptual understanding, students' conceptions of particulate nature of matter and vapor pressure and its associated concepts. The subsequent section provides an overview of constructivist view of learning.

2.1. Constructivist View of Learning

The questions of "how learners reach complete and scientific understanding?" and "how meaningful learning occurs in the best way?" have always been important issues for education. Educational researchers are in pursuit of the answers of these questions.

Meaningful learning is accepted as part of higher order thinking that requires grasping the relations between two or more ideas representing old and new. Ausubel (1968) thinks that a student's prior knowledge is an important factor in determining active learning in being able to learn new concepts. Ausubel and Robinson (1969) claim that the material presented to the learners should be capable of being related to their lives in some sensible fashion, and it is also expected that new information should fit into the current whole of learners' cognitive structure to accomplish relating that in a sensible way. Otherwise, the demanded learning process ends with rote learning (Ivie, 1998).

Ausubelian theory provides a theoretical basis for constructivism, and constructivist ideas have been prevalent for the last few decades by taking place of the traditional view of knowledge. Most scholars consider constructivism as an epistemology, that branch of philosophy that focuses on the nature, methods, and limitations of human knowledge (Atwater, 1996). According to constructivist view; knowledge is constructed in the mind of the learner, and the knowledge must have possessed the feature of viability; that is, it must work. From this perspective, knowledge cannot be judged anymore in terms of being true or false as it does according to traditional perspectives (Bodner *et al*. 2001).

Duffy and Jonassen (1991) claimed that “meaning is imposed on the world by us” (p.3) appeared as an alternative epistemological base to the objectivist tradition supporting the idea of that “meaning exist in the world independently of the experiences” (p.3). In accordance with this perspective, the researchers state that constructivism describes learning as a construction process carried out by the individual learner through meaningful interactions within the knowledge domain. This statement emphasizes the importance of personal interpretation of experiences, because learning is an active process that meaning is developed on the basis of experience. Conceptual growth comes then by sharing experiences in a cumulative way (Duffy and Jonassen, 2013).

As it is stated above, there is always a quest for the best in education and constructivist ideas are quite different from the traditional.

There are some critics on the practicality of constructivism. Cobb (1994) emphasizes that there is a dichotomy between situations in practice where students construct their own knowledge and where it is transmitted to them. The researcher states that the critical issue becomes the nature or quality of those socially and culturally situated constructions instead of whether students construct their own knowledge.

There are many studies supporting constructivism in science education. Millar and Driver (1987) state that science knowledge is constructed as personally and socially. Science learning occurs when students interact with others; thus, the science ideas in their minds become modified, extended or change during the process.

Social constructivism emphasizes the contributions of social interactions to the construction of self and it is associated with Vygotsky’s work (1978). Vygotsky focuses on social relationships instead of individual and accepts the language as the mediator of thought. He emphasizes the role of teachers and peers on learning and claims that learners construct their understanding through internalization process. For example, science concepts are first negotiated between students before being incorporated into the learners’ cognitive structures (Scott, 1996).

Similar to Vygotsky, Gergen (1995) explains that the fundamental concern of social constructivism is the language. It begins with the language, not with the external world from the exogenic tradition (world centered), nor the individual mind from the endogenic tradition (mind centered). He agrees that there is only a social mind, not an individual one. Gergen admits that the knowledge is constructed through social interactions in the medium of language. Therefore, it is emphasized that the interactions of science teachers with students, and the roles of these interactions in the learning process must be further investigated.

Besides, the theory of constructivism points out the way of how to modify laboratory activities to increase understanding in science. Shiland (1999) states that learners must be dissatisfied with their present knowledge, learning has a social component, and it needs application. This study proposes that increasing the cognitive activity of the learner develops understanding in science, as constructivist view says that learning requires mental activity. As a result, performing activities putting more responsibility on the learner, and giving less specific directions are offered although such activities require more time to implement.

In this part of the literature review, the adopted epistemology of current study has been summarized. The next part is a review of literature focuses on conceptual understanding.

2.2. Conceptual Understanding

There are many studies investigating students' understandings of scientific concepts and phenomena after being aware of the importance of constructivist view in education (Driver *et al.*, 1999). These studies have a consensus about students' ideas in science education. This consensus (Champagne *et al.*, 1983; Osborne and Wittrock, 1983; West and Pines, 1985) is that:

- Students already have their own ideas and views about many science topics before receiving any formal education on the subject.

- Although students' own ideas are often different from views of scientists, they are sensible and useful for them.
- Students' preconceptions are resistant to change by traditional instructional methods because students' ideas are consistent for them.

Students' ideas were labeled as alternative frameworks or misconceptions (Driver and Easley, 1978), children's science (Gilbert *et al.*, 1982) and naive beliefs (Caramazza *et al.*, 1981). Realizing students' own ideas is important in education because teaching the topic in the different levels of thinking by taking into consideration students' ideas helps students to connect links between the levels (Hinton and Nakhleh, 1999; Russell *et al.*, 1997; Tasker, 1992; Tasker *et al.*, 1996).

To help students in understanding the chemical concepts, it has been developed different visual representations to build a bridge that connects concrete and abstract concepts. There are three various levels of chemical representation of matter. It is determined to be important for conceptual understanding of chemical concepts. The levels of chemical representation are macroscopic, symbolic, and submicroscopic or particulate (Gabel, 1998; Johnstone, 1991; Treagust *et al.*, 2003). In macroscopic representation, chemistry is represented by observable phenomena, such as temperature or color changes of the system during chemical reaction. The macroscopic representation comprises real chemicals and observable chemistry phenomena.

For example, a macroscopic representation of water would include a description of physical state at various temperatures. In symbolic representations, chemistry is described by using symbolic language, such as mathematical equations, chemical equations and molecular formulas. For example, the symbolic representation of water may be represented by symbols of hydrogen (H) and oxygen (O) as in its molecular formula (H_2O). In particulate representations, chemistry is represented with particulate drawings or dynamic molecular models in term of its constituent atoms, molecules, and ions. The particulate level of water is defined by Gabel (2003) as "a collection of particles (molecules) that have attractive forces between them and that consist of the atomic particles of hydrogen and oxygen" (p. 70). Particulate theory of matter refers to atomic, molecular, and ionic interactions that lead to observable chemistry phenomena (Bunce and Gabel, 2002; Gabel, 1999; Johnstone, 1991).

Researchers have shown that the difficulties in understanding the particulate model of matter and its collective behavior were evident (Johnson, 1998; Krnel *et al.*, 1998). By the side of the nature of particles themselves, the difficulties meet frequently on the space between the particles, the motion of particles, the relative spacing between particles in the three states, and the attractions between particles (Johnson, 1998). Dow *et al.* (1978) informed that although the majority of junior high school students accepted the idea of particle motion in the liquid and gas state, nearly a third of them demonstrated that there was no particle motion in the solid state. These students have also indicated difficulties in understanding the collective behavior of particles. Lee *et al.* (1993) pointed out that students consider molecules of ice as ‘solid molecules’, or molecules of water in liquid phase as ‘liquid molecules’, and molecules undergo the same changes when phase changes in the substances, such as melting or evaporation, occur, that is, the molecules can also melt or evaporate.

As expected, it is clear that if students cannot understand the particulate nature of matter, they may have difficulties in understanding its phase changes. For instance, difficulties have been reported for phase changes, including melting, boiling, evaporation, and condensation because students cannot grasp the space between the particles, the motion of the particles, the relative spacing between particles in different phases and the attractions between particles easily (Stamovlasis *et al.*, 2012). Osborne and Cosgrove (1983) argued that students could not understand the mechanism of the phase change of matter. For example, students frequently believe that the bubbles were made of a mixture of hydrogen and oxygen or air in the case of boiling water. Students often cannot make sense of the formation of vapor above the surface of boiling water. Studies done on evaporation and melting showed that students have not provided the clear explanations for the changes of state (Bar and Travis, 1991; Johnson 1998). In view of these findings, Johnson (1998) pointed out that these results are related to the lack of understanding of the concept of the particulate nature of matter. When a student cannot understand what a substance is, its states are in fact unexplored and the changes of states cannot be explained.

Conceptual understanding levels and alternative conceptions of students about chemical concepts have been studied in both national and international literature. Many studies have emphasized that a significant number of students held alternative conceptions and had difficulties in understanding the concepts that they have alternative conceptions (Burrows and Mooring, 2015; Cokelez and Dumon, 2005; Dhindsa and Treagust, 2009; Nakiboğlu, 2003; Peterson and Treagust, 1989; Uyulgan *et al.*, 2014).

The basic subjects in general chemistry facilitate students to develop their knowledge in other chemistry fields (Burrows and Mooring, 2015; Duis, 2011). As a result, basic chemistry concepts that form the base on chemical systems, such as bonds, molecular structures, and reaction mechanisms, are needed to be learned well (Fensham, 1975).

The next part is a review of literature focusing on the particulate nature of matter and its importance in chemistry learning.

2.3. Students' Conceptions of Particulate Nature of Matter

Nakhleh (1992) stated, "concepts are considered to be the set of propositions that a person uses to infer meaning for a particular topic, such as the nucleus of an atom" (p.191). For this reason, particle theory of matter concept is a key concept that entails a set of propositions that are used to define the nature of matter. De Vos and Verdonk (1996) summarized the key concepts of the particulate nature of matter as;

- All matter is composed of particles. These particles cannot be seen because they are too small. They can be represented as dots or circles in drawings.
- All particles move. Their average kinetic energy and the temperature is directly related.
- The empty space between particles is larger when it is compared to the volume occupied by particles in a gas. Particles of a gas are randomly distributed.
- Between particles; there is mutual attraction. The magnitude of attraction decreases rapidly with increasing distance between particles. (de Vos and Verdonk, 1996, p.659)

Johnstone (2000) indicated that students have difficulty in moving among the domains of three levels of chemical knowledge. It is especially emphasized that students find difficult molecular level knowledge and need help in understanding it in order to avoid developing alternative conceptions that can prevent subsequent learning.

According to the previous studies as to the particulate theory of matter, students' understanding is relatively limited (Albanese and Vicentini, 1997; Johnson, 1998a; Nakhleh *et al.*, 2005). Students believe that matter is continuous and the particles are "small portions of the substance" (Ben-Zvi *et al.*, 1986). It is proposed that students accept particles as small pieces of an object with the same properties (Krnel *et al.*, 1998). Additionally, students regard that there is no space between particles (Griffiths and Preston, 1992). It is also investigated the relationship between the conception of atom and the structure of molecules (Ben-Zvi *et al.*, 1986). Majority of the students who correctly described the properties of atom visualized the bonding between the particles in substances.

Another research area about the particle theory is that on changes of state of matter. It is suggested that the composition of bubbles in boiling water consist of air, oxygen or hydrogen, heat, and steam. (Johnson, 1998a). Results from another study showed that students face problems with the concept of evaporation and condensation (Johnson, 1998b). Students have trouble conceding the opinion that steam can be present in the air.

Apart from general measurements, researchers employed specifically designed instruments to assess students' conceptual understanding of the particulate nature of matter (PNM). For example, Williamson and Abraham (1995) employed the Particulate Nature of Matter Evaluation Test (PNMET) to find that whether the animations improved the students' conceptual understanding at the particulate level. They have shown that the students participated in the test scored higher on the PNMET, showing that the computer animations improved students' mental models and conceptual understanding in chemistry at the submicroscopic level. In a similar way, Yezierski and Birk (2006) found that student's alternative conceptions as to PNM were connected to phases and phase changes of matter. To investigate the situation, they constructed an instrument called as the Particulate Nature of Matter Assessment. The instrument was composed of 20 multiple-choice items involving five distinct topics about particulate nature of matter. By investigating the pre- and posttest results, it is argued that the atomic and molecular level animations helped students in composing better mental models and reorganizing alternative conceptions as to particular properties.

Familiarity with the particulate nature of matter is fundamental to understand almost all chemistry concepts, because particulate nature of matter is important to learn chemistry meaningfully with deep understanding of chemical concepts. (Harrison and Treagust, 2002). In addition to studies about particulate nature of matter, there are some research about possible associations between students' understandings of the particulate nature of matter and the other concepts in chemistry.

Adadan (2014) investigated the influence of pre-service chemistry teachers' understanding of the particle nature of matter on their conceptual understanding of solution chemistry. The goal of the study has been given as "to describe the level of understanding of specific solution chemistry concepts of a group of participants with a high understanding of the particulate nature of matter (PNM) and a group with a low understanding of the PNM before and immediately after multi representational (MR) instruction" (Adadan, 2014, p.219). Results from the study suggested "the participants with a high understanding of the PNM were more likely to develop a scientific understanding of a particular concept (e.g., supersaturated solutions) in solution chemistry even without viewing the available visual particulate representations of the phenomenon" (p. 226).

Othman *et al.* (2008) investigated the relationship between students' conceptions of the particulate nature of matter and their understanding of chemical bonding. They administered a two-tier multiple-choice instrument to 260 Grades 9 and 10 students. The findings revealed possible correlations between students' understanding of the particulate nature of matter and chemical bonding. Furthermore, the results of this study provided useful suggestion such that students' limited understanding of the particulate nature of matter influenced their understanding of chemical bonding.

2.4. Vapor Pressure and Its Associated Concepts

It is obvious that chemistry has many abstract concepts, students cannot observe directly many chemical phenomena, and they have difficulty in grasping abstract concepts (Karaçöp *et al.*, 2009). Vapor pressure is one of these concepts that have been regarded as difficult in chemistry curriculum by students due to its abstract nature (Canpolat *et al.*, 2006; Gopal *et al.*, 2004). Students who have their own ideas when they come into the classroom are ready to develop many alternative conceptions about the vapor pressure. Vapor pressure is one of the most important and complex subjects in chemistry that many students have difficulties to grasp its concepts and characteristics correctly. To understand the vapor pressure and their characteristics, the students need to understand its associated concepts such as evaporation and boiling.

Costu and Ayas (2005) explored secondary school students' understanding of evaporation. A test consisting of four open-ended items was applied on 313 secondary school students at different levels. In addition, clinical interviews were undertaken with 12 students. According to the results of this study, most of the secondary school students showed lack of understanding with several alternative conceptions on evaporation concept.

Luoga *et al.* (2013) aimed to identify high school students' alternative conceptions about colligative properties including boiling point elevation and freezing point depression. A piloted diagnostic test comprising of four open-ended questions was administered to 105 high school students and several alternative conceptions related to colligative properties were detected.

Pinarbasi *et al.* (2009) also studied on students' alternative conceptions related to colligative properties. 78 prospective chemistry teachers participated to the study voluntarily and a diagnostic test consisting of four open-ended questions was used for data collection. Findings showed that prospective chemistry teachers have difficulty in understanding colligative properties and many alternative conceptions related to colligative properties were identified.

According to the findings of a study conducted by Azizoğlu *et al.*, (2006), the majority of the students (75% of the participants as undergraduate pre-service teachers) showed misunderstandings about the equilibrium vapor pressure of a liquid when a nonvolatile solid is dissolved in the liquid and only 15% of the students could give a complete and correct answer so that evaluated as “sound understanding”.

Pinarbasi and Canpolat (2003) examined undergraduate students’ understanding of some concepts relating to solution chemistry. An instrument was designed to test students’ understanding of the concept of vapor pressure lowering, the reasons for this phenomenon, and also the students’ understanding of the relationship between vapor pressure and boiling point. The instrument is a diagnostic test including some concepts in solution chemistry such as unsaturated, saturated and supersaturated solutions, physical properties of solutions and solubility of gases. In addition to asking the participants to fill out the instrument, the researchers also interviewed some of the participants who were chosen randomly. According to the study’s results related to vapor pressure, more than the half of the participants had the idea of “because of the attractive forces between solute particles and solvent particles, the vapor pressure of a solution is less than that of pure solvent.” The researchers also identified that most of the participants believed in the statement of “boiling liquids at atmospheric pressure have different vapor pressures”.

Another study conducted by Canpolat *et al.*, (2006) searched about undergraduate students’ alternative conceptions related to evaporation and vapor pressure. The researchers used open-ended diagnostic questions and semi-structured interviews to determine the understanding of the students. This study supported the other studies claiming that students have weaknesses in grasping evaporation and vapor pressure concepts by identifying many alternative conceptions (see Table 2.1).

Canpolat (2006) revealed that students did not conceptualize the concepts of evaporation, evaporation rate, and vapor pressure correctly, and they hold several alternative conceptions, although students start to learn about these concepts by beginning from earlier classes. Therefore, the researcher argues that alternative conceptions are resistant to change over time. The researcher also claims that this resistance can be caused by poor representations in textbooks; therefore, it supports the idea of science textbook writers and teachers are not adequate enough to take into account the students' previous conceptions and alternative conceptions (Calik and Ayas, 2005).

Canpolat and Pinarbasi (2011) developed a two-tier multiple-choice diagnostic instrument to investigate students' conceptions and alternative conceptions about evaporation, evaporation rate and vapor pressure. The test was applied on 208 students engaged with Chemistry Teaching Program and some alternative conceptions were detected (see Table 2.1).

Another study conducted by Canpolat and Pinarbasi (2012) investigated the prospective chemistry teachers' views on boiling and vapor pressure. Data was collected from 18 senior prospective chemistry teachers and discussions were used as data-gathering method. Results of the study showed that prospective chemistry teachers have serious alternative conceptions regarding boiling and vapor pressure (see Table 2.1).

Demirbag and Kingir (2017) aimed to analyze pre-service science teachers' conceptual understanding about boiling. Written texts and audio recordings were used as data collection methods. According to the results, pre-service science teachers have conceptual difficulties about boiling (see Table 2.1).

Costu *et al.* (2007) searched about undergraduate students' conceptual understanding of the boiling concept. Boiling Concept Test (BCT) consisting of nine questions was applied to 52 participants and results revealed alternative conceptions related to boiling and vapor pressure (see Table 2.1).

Another study conducted by Costu *et al.* (2010) used Evaporation Conceptual Test (ECT) consisting of eight items. Researchers investigated the undergraduate students' understanding of the evaporation concept. This study showed that undergraduate students have alternative conceptions related to vapor pressure in addition to alternative conceptions related to evaporation (see Table 2.1).

Tumay (2014) revealed prospective chemistry teachers have many alternative conceptions about vapor pressure, which are similar to those reported in the literature. The common alternative conceptions derived mainly from three faulty mental models of vapor pressure. Firstly, vapor pressure of a liquid depends on the total number of vapor particles; the second one is that once the liquid–vapor equilibrium is established, the number of vapor particles is fixed and does not change regardless of the external effects on the system; and finally the vapor pressure is exerted only onto the surface of the liquid.

All of these studies supports the idea that vapor pressure concept is very difficult to grasp as coherently. The summary of all research studies on students' conceptual understandings and alternative conceptions about the vapor pressure and its associated concepts are included in Table 2.1.

Table 2.1. The summary of studies on students' conceptual understandings and alternative conceptions about the vapor pressure and its associated concepts.

Alternative Conception	**Authors**
• Vapor pressure of a solution is less than that of pure solvent because of the attractive forces between solute particles and solvent particles.	Azizoglu *et al,* 2006; Pinarbasi and Canpolat, 2003
• Vapor pressure depends on the amount of liquid.	Azizoglu *et al,* 2006; Canpolat *et al*, 2006; Canpolat and Pinarbasi, 2011
• Vapor pressure depends on the volume of container.	Azizoglu *et al,* 2006; Canpolat and Pinarbasi, 2011
• Vapor pressure values of boiling liquids at atmospheric pressure are different.	Azizoglu *et al,* 2006; Canpolat *et al*, 2006; Canpolat and Pinarbasi, 2011
• Evaporation is caused by temperature differences between the liquid and its environment.	Canpolat, 2006; Canpolat and Pinarbasi, 2011; Costu and Ayas, 2005
• Evaporation rate depends on whether the container is open or closed.	Canpolat, 2006; Canpolat and Pinarbasi, 2011
• Evaporation rate decreases in time.	Canpolat, 2006; Canpolat and Pinarbasi, 2011
• Evaporation does not occur anymore when the liquid-vapor equilibrium is established.	Canpolat, 2006
• Evaporation rate depends on the surface area of liquid.	Canpolat, 2006; Canpolat and Pinarbasi, 2011
• When the volume of the vapor in equilibrium with its liquid changes, the value of vapor pressure changes at constant temperature.	Canpolat, 2006; Canpolat *et al*, 2006
• If some inert gas is added to the container at liquid-vapor equilibrium, vapor pressure changes.	Canpolat, 2006; Canpolat and Pinarbasi, 2011

Table 2.1. The summary of studies on students' conceptual understandings and alternative conceptions about the vapor pressure and its associated concepts (cont.)

Alternative Conception	Authors
• The pressure exerted onto surface of liquid by the particles at vapor phase in a closed container is called as vapor pressure.	Canpolat *et al*, 2006; Tumay, 2014
• During boiling, particles at the vapor phase causes pressure called as vapor pressure.	Canpolat *et al*, 2006; Costu *et al*, 2007
• Vaporization starts with boiling.	Canpolat *et al*, 2006
• Evaporation does not occur without heating.	Canpolat *et al*, 2006
• Vapor pressure depends on altitude.	Canpolat and Pinarbasi, 2011
• The total number of vapor particles affects vapor pressure of a liquid.	Canpolat and Pinarbasi, 2011; Tumay, 2014
• After boiling, evaporation occurs for a while. The pressure of vapor in equilibrium with the liquid is vapor pressure.	Canpolat and Pinarbasi, 2012
• Pressure exerted by particles of liquid is vapor pressure.	Canpolat and Pinarbasi, 2012
• Pressure of the particles just below the liquid surface is vapor pressure.	Canpolat and Pinarbasi, 2012
• Vapor pressure is the pressure inside the bubbles.	Canpolat and Pinarbasi, 2012
• Evaporation does not occur if boiling does not occur.	Costu and Ayas, 2005; Costu *et al*, 2010;
• Evaporating particles give heat to the environment during vaporization.	Costu and Ayas, 2005
• Vapor of water includes hydrogen and oxygen gases.	Costu and Ayas, 2005; Costu *et al*, 2010
• The vapor pressure of different substances is the same when they are heated by using identical heaters.	Costu *et al*, 2007
• Evaporation occurs at everywhere of a liquid.	Costu *et al*, 2010
• When the water is heated, its volume increases and pressure decreases.	Demirbag and Kingir, 2017
• Boiling does not occur without heating.	Demirbag and Kingir, 2017
• Interactions between solute and solvent cause boiling point elevation and/or freezing point depression.	Luoga *et al*, 2013; Pinarbasi *et al*, 2009
• Liquids with higher density have lower/higher boiling/freezing temperatures than liquids with lower density.	Luoga *et al*, 2013; Pinarbasi *et al*, 2009
• The number of vapor particles is constant regardless of the external effects applied on the system when the liquid-vapor equilibrium is established.	Tumay, 2014

As seen in Table 2.1, there are many qualitative and quantitative research studies on students' conceptual understandings and alternative conceptions about the vapor pressure and its associated concepts. Those studies identify the common alternative conceptions by using different data-gathering methods such as diagnostic tests or interviews. According to the results of the summarized studies on the table, it is obvious that most of the participants have alternative conceptions related to vapor pressure and its associated concepts. Although the participants involved in these research studies related to vapor pressure are at different grades; such as high school students, undergraduate students, prospective teachers or chemistry teachers, they focus on the alternative conceptions and results show that participants in different grade of levels can have the same alternative conceptions regardless of age and statue. However, there is no research study investigating the relationship between the concepts of particulate nature of matter, which is a key concept to many other chemistry concepts such as vapor pressure, and vapor pressure, which alternative conceptions are easily developed by many participants. The current study aims to fill the deficiency on this issue.

3. METHODOLOGY

It was followed a convergent mixed-method design in which qualitative and quantitative data collection and analysis methods were used. The data collection was completed in two phases: First, the participants filled out the particulate nature of matter diagnostic instrument, and then they were interviewed on the topic of vapor pressure. The mixed method study explored the association between first-year college students' understanding of particulate nature of matter (PNM) and their understanding of vapor pressure. More specifically, the goal was to identify and describe the level of understanding of vapor pressure across the two groups, namely a group with a high understanding of the PNM and a group with a low understanding of the PNM. Therefore, the current study attempted to answer the following research questions:

- How do the groups of first-year college students with a high understanding of the PNM and a low understanding of PNM compare in terms of their understanding of vapor pressure?
- What level of conceptual understanding of specific vapor pressure concepts are demonstrated by the groups of first-year college students with a high understanding of the PNM and a low understanding of PNM?

The present study provides information related to the following sub-sections. First, the pilot study will be described. Second, the research design of the study will be identified. Third, participants of the study will be presented with the demographic information of the sample. Fourth, data collection procedure will be introduced. Finally, data analysis related to the study will be discussed.

3.1. The Pilot Study

A pilot study was conducted in a public university with first-year college students who were attending to general chemistry course. Totally, 52 students, other than the sample of the current study, participated in the pilot study that included the testing of written instrument called the two-tier Particulate Nature of Matter Diagnostic Instrument

(PNM-DI). The participants responded to the questions in the PNM-DI within 40-minutes class period. For each question, the participants also made further explanations about their answers. The Cronbach's Alpha coefficient of the instrument was found to be 0.616. The Cronbach Alpha coefficients of the main sources from which the items of PNM-DI were utilized were 0.65 (Treagust *et al.*, 2011) and 0.78 (Yezierski, 2003). These values were close to the calculated Cronbach Alpha coefficient of PNM-DI. The development of the instrument will be further discussed in Data Collection section in this chapter.

3.2. The Research Design

This convergent mixed method study adopted a quasi-experimental comparison group design, along with qualitative data collection and qualitative and quantitative data analysis procedures (Creswell, 2012). This methodological design was used to compare the nature of conceptual understandings of vapor pressure held by the groups of participants with a high understanding of the PNM and a low understanding of the PNM. In other words, how the extent of participants' understandings of the PNM interplayed with their conceptual understandings of vapor pressure was analyzed through this particular design.

3.3. Participants of the Study

The potential participants of this study were the first-year college students who were enrolled in General Chemistry I course. The participants were recruited in a voluntary manner from a public university in Istanbul. Forty-eight first-year college students, who were enrolled in General Chemistry I course, volunteered to participate in the study.

The participants included 29 female (60%) and 19 male (40%). The participants were studying in one of the following programs: chemistry, teaching of chemistry, teaching of physics, chemical engineering, and molecular biology and genetics departments. Departmental population of participants can be seen in Table 3.1 below.

Table 3.1. Departmental distribution of participants.

Department	# of Female Participants	# of Male Participants
Chemistry	7	7
Teaching of Chemistry	10	5
Teaching of Physics	5	2
Chemical Engineering	4	3
Molecular Biology and Genetics	3	2

A permission letter was obtained from Institutional Review Board for Research with Human Subjects (INAREK) to conduct individual interviews with the participants. The permission letter was presented in Appendix A. In addition, the participants were provided with information about the study, and oral consent of each participant was obtained.

3.4. Data Collection

Data were collected through diagnostic tests and interviews. The Particulate Nature of Matter-Diagnostic Instrument (PNM-DI) and Vapor Pressure Interview Protocol were used to diagnose participants' understanding of the particulate nature of matter and vapor pressure concepts, which are included in college chemistry curriculum.

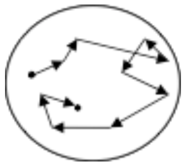
3.4.1. Diagnostic Test

The questionnaire which entitled Particulate Nature of Matter–Diagnostic Instrument (PNM-DI) was composed of selected two-tier multiple choice items, which were used for ascertaining students' conceptions of PNM in the previous studies (Treagust *et al.*, 2011; Yezierski, 2003). A first tier looked for a content response, and a second tier ascertained the reason for that response (Treagust, 1995). One of the items from the PNM-DI is shown in the Table 3.2 as an example.

The selected questions translated into Turkish, and a panel of experts checked the validity for the Turkish version. The PNM-DI test included a total of 14 multiple choice questions, aiming to assess the participants' understanding of the following aspects of particle theory of matter: matter is made up of particles, the arrangement and spacing between particles, the motion of particles, the existence of interactions between particles (see Table 3.3).

Table 3.2. Selected item from PNM-DI.

The diagram represents the random zigzag movement of smoke particles (referred to as Brownian motion) when smoke in a glass container is viewed under a microscope.



Which conclusion can you draw from this observation?

A. Smoke particles are floating in air.
B. Air consists mainly of empty space.
C. Air is made up of tiny particles moving randomly.
D. Smoke particles are larger than air particles.

The reason for my choice of answer is:

1. Smoke particles are large
2. There are large spaces between the smoke particles
3. Colliding smoke particles move in a random zigzag manner
4. Air particles are constantly colliding with smoke particles
5. Other reason:………………………………………………………………

The complete instrument can be found in Appendix B. The concepts assessed by each item of the PNM-DI can be seen in the Table 3.3.

Table 3.3. Concepts included in the PNM-DI instrument.

Item	Concepts	Objectives	Source
1	Phase change; structure of particles	To describe a phase change at the submicroscopic level	Yezierski, 2003
2	Phase change; size of particles	To examine the effect of phase change on the size of particles	Yezierski, 2003
3	Dissolving; movement of particles	To explain diffusion by the movement of particles	Treagust *et al.*, 2011
4	Dissolving; movement of particles	To explain diffusion by the movement of particles t	Treagust *et al.*, 2011
5	States of matter; movement of particles	To describe the movement of particles in gaseous phase	Treagust *et al.*, 2011
6	Dissolving; movement of particles	To explain dissolution by the movement of particles	Treagust *et al.*, 2011
7	Phase change; bonding	To examine the intermolecular forces during a phase change	Treagust *et al.*, 2011

Table 3.3. Concepts included in the PNM-DI instrument (cont.)

Item	Concepts	Objectives	Author
8	Phase change; bonding	To examine the effect of phase change on the particle behavior	Yezierski, 2003
9	Energy change; movement of particles	To examine the effect of temperature change on the particle behavior	Yezierski, 2003
10	Phase change; bonding	To examine the intermolecular forces during a phase change	Yezierski, 2003
11	Phase change; structure of particles	To examine the structure of particles during a phase change	Yezierski, 2003
12	Phase change; movement of particles	To examine the effect of phase change on the particle behavior	Yezierski, 2003
13	Phase change; movement of particles	To examine the effect of phase change on the particle behavior	Yezierski, 2003
14	Phase change; bonding	To examine the intermolecular forces during a phase change	Yezierski, 2003

If an instrument is to be used in any kind of decision-making, it is essential that the instrument should be valid. The simplest way of determining whether an instrument is sufficiently valid is content validity (Lewis *et al.*, 1995). Content validity answers the question "Does the test measure the instructional objectives?". A panel of experts, including a chemistry education professor, and two chemistry professors, established the content validity of the PNM-DI instrument used for the current study.

3.4.2. Interviews

Interviews are a systematic way of talking and listening to participants. The interviewer often uses open-ended questions. There are many types of interviews that include structured, semi-structured and unstructured interviews (Glesne, 1999). A structured interview is sometimes called a standardized interview. On the other hand, semi-structured interviews are non-standardized and are frequently used in qualitative analysis. In this type interview the order of the questions can be changed depending on the direction of the interview.

The current study used semi-structured interviews to analyze the participants' understanding of vapor pressure. Interview protocol was presented in Appendix C. First few interviews were conducted as the pilot of interviews. Because the interviews provided sufficient data for the analysis, they were continued to be conducted as in the pilot study. During the interviews, the participants explained some terms related to vapor pressure and completed six tasks involving two concepts that are the nature of vapor pressure and factors affecting vapor pressure. The nature of the interview tasks can be seen in Table 3.4.

Table 3.4. The nature of the interview tasks.

Tasks	**Description of Tasks**
The Nature of Vapor Pressure (Verbal)	
1a	Define and describe the concept of evaporation.
1b	Define and describe the concept of boiling.
1c	Define and describe the concept of vapor pressure.
Factors Affecting Vapor Pressure (verbal, macroscopic and submicroscopic)	
2	Given the macroscopic view of some water in a closed container at 25^{o}C with a submicroscopic pictorial representation of water and vapor. It was asked: Consider "What happens to the system if the volume of vapor becomes half?" Draw and explain how you imagine water vapor to the boxes representing the particles at the submicroscopic level Describe how vapor pressure changes when the volume of vapor becomes half.
3	Given that two closed containers are in the same size. One contains 50 mL of water, and the other one contains 100 mL of water at equilibrium with its vapor at 25^{o}C. Given the pictorial particulate representations of water for both containers, it was asked: "Compare the amount of water vapor above liquid in both containers by drawing the submicroscopic pictorial representation of vapor, and explain your drawings." Compare and contrast the vapor pressure of the two systems with respect to your submicroscopic pictorial representation.
4	Given the three open containers with 100 mL water, 100 mL ethyl alcohol, and 100 mL 15% NaCl (aq) solution in each. It was asked: "Compare and contrast the vapor pressure of each system during boiling, and explain your reasoning."
5	Given the two closed containers with an equal volume. One contains 100 mL of water, and the other contains 100 mL of acetone at 25^{o}C. It was asked: "Consider how you imagine the vapor above each liquid at the particulate level." Draw submicroscopic pictorial representation of vapor for both containers, and explain your drawing. Compare and contrast vapor pressure of the two systems, and explain your reasoning.
6	Given the three closed containers, each with having 50 mL water. The first one is at 0^{o}C, the second one is at 30^{o}C, and the third one is at 70^{o}C. It was asked: "Compare and contrast the vapor pressure of three systems along with explaining your reasoning."

As each participant completed each task, the researcher usually did not accept the initial responses and asked for further explanation (Glesne, 1999). Each interview typically lasted 25 to 40 minutes although no time limit was set for the interviews. All of the tape-recorded interviews of all participants were transcribed. The large number of interviews in the data analysis shows the strength of the current study.

Research asserted that students should be able to represent their understanding in multiple levels; that are macroscopic, submicroscopic and symbolic; to show their conceptual understanding (Cheng and Gilbert, 2009; Kozma, 2003). Consistent with this claim, the current study's tasks reveal the participants' understanding of vapor pressure by using multiple levels of representation indicating their understanding.

3.5. Data Analysis

This study employed both quantitative and qualitative data analysis procedures. The total PNM-DI scores of each participant were calculated; frequency distribution of the scores and the skewness of score distribution were analyzed with respect to the total PNM-DI scores. Pearson's Coefficient of Skewness (Sk_2 – uses median) was calculated to be 0.19 (Doane and Seward, 2011), which was in the acceptable range of normal distribution for a sample of 40-50 participants. Note that the acceptable coefficient range for skewness is in between -0.594 and +0.539 (see Doane and Seward, 2011).

For research question 1, both the participants' responses to the PNM-DI and their responses in the interview on vapor pressure concepts were analyzed. The data from the PNM-DI were coded and analyzed by using statistical procedures. The participants' responses to each item in the PNM-DI were numerically coded. The numeric point of one (1) was assigned for each scientifically accurate response, and the point of zero (0) was assigned for all the other responses. The participants got (1) point if both tiers of the question are scientifically accurate so that each participant had a total numeric score of PNM-DI. A total of 14 points was possible on the test. The median score of all participants' total PNM-DI scores was found to be 9.00, and the participants were grouped with respect to their total PNM-DI scores. The participants whose PNM-DI score is higher than the median score were classified in High PNM Understanding Group and the participants whose PNM-DI score is lower than the median score were included in Low PNM Understanding Group. The high PNM group included 23 participants, and the low PNM group consisted of 25 participants.

Interviews were transcribed. The participants' verbal and pictorial responses to each task on the interviews were divided into units. Coding was achieved by comparing the participants' responses to the scientific coding criteria identified for each task. The codes and descriptions of the identified scientific criteria are given at Table 3.5. There were 39 units, including verbal responses and drawings. Each unit was given a numeric point of (1) or (0) by comparing with the scientific criteria (see Table 3.5), so the highest possible score that can be gained from the interviews was 39. The numeric point one (1) was assigned for each unit if the response met the scientific criteria, and the numeric point (0) was assigned if the response included alternative conceptions or participants provided irrelevant explanations. Furthermore, two chemistry teachers marked eight participants' responses, which were randomly selected; in order to ensure inter-rater reliability, and 92% agreement was established. Thus, each participant had a total numeric score, indicating his or her understanding of vapor pressure. The alternative conceptions that emerged from data were also recorded.

Table 3.5. Scientific criteria of vapor pressure.

Codes	**Description**
The Nature of Vapor Pressure	
Task 1a	***Evaporation***
S-FLG1	Intermolecular forces between particles weaken during evaporation.
S-MLG1	Movement of particles increases when the liquid turned to gas.
Task 1b	***Boiling***
S-AP1	Boiling starts when the vapor pressure of a substance equals to the atmospheric pressure.
S-FLG1	Intermolecular forces between particles weaken during boiling.
S-MLG1	Movement of particles increases when the liquid turned to gas.
Task 1c	***Vapor Pressure***
S-Eq1	Equilibrium is a balanced condition of a closed system. It is not stable, forward and reverse changes are at the same rate in the equilibrium.
S-VP1	The pressure of a gas in a system, that liquid-vapor equilibrium is established, is its vapor pressure. Gas particles exert pressure on liquid by hitting on the surface.

Table 3.5. Scientific criteria of vapor pressure (cont.)

Codes	Description
Factors Affecting Vapor Pressure	
Task 2	***Vapor Pressure in Containers with Different Volumes***
S-NPVis2	Particles in upper box is shown in gaseous phase, on the other hand particles in bottom box is shown in liquid phase. Same number of particles is shown in gaseous phase.
S-Eq2	Equilibrium between liquid and gaseous phase of the substance is provided again when some particles in gaseous phase transform into liquid phase.
S-NPVer2	Although there is same number of particle in unit volume for both cases, total number of particles in gaseous phase decreases.
S-VP2	Equilibrium condition is provided again at the same temperature after some particles in gaseous phase transform into the liquid phase, so pressure does not change.
Task 3	***Vapor Pressure for Containers with Different Amounts of Liquids***
S-NPVis3	Both boxes contain the same number of particles in gaseous phase.
S-Eq3	There is equilibrium between liquid and gaseous phase of a substance in both cases. Both evaporation and condensation reactions continue to occur at the same rate.
S-NPVer3	Although there exist the same number of gaseous particles in the boxes representing the unit volume for both cases, Figure I representing less amount of liquid contains more gaseous particles in total on liquid than Figure II representing more amount of liquid.
S-VP3	There are more gaseous particles on liquid at Figure I. The container at Figure II has less gaseous particles on liquid. Yet, the unit volume of both systems has the same number of gaseous particles. They exert the same pressure on liquid, and the vapor pressure of both systems is the same. So vapor pressure does not depend on the volume of liquid.
Task 4	***Vapor Pressure for Different Liquids in Open Containers***
S-NPVer4	There exist the same number gaseous particles on different liquids during boiling.
S-VP4	A liquid boils when its vapor pressure equals to the pressure above it. Actually the vapor pressure within a bubble must be a tiny bit greater than the surrounding pressure.
S-AP4	Gaseous particles in air on liquid surface exert pressure, and they prevent particles of liquid to transfer into gaseous phase. When bubbles move due to having enough energy to overcome the pressure above them, boiling occurs.
S-MLG4	Movement ability of particles increases when they transferred into gaseous phase from liquid phase, because the energy they gained for phase change increases the movement by overcoming the bonds and weakens the intermolecular forces between particles.

Table 3.5. Scientific criteria of vapor pressure (cont.)

Codes	Description
Task 5	***Vapor Pressure for Different Liquids in Closed Containers***
S-NPVis5	More gaseous particles are shown in the box representing the unit volume of liquid whose intermolecular force is weaker. On the other hand, more gaseous particles are shown in the box representing the unit volume of the liquid whose intermolecular forces are stronger.
S-FLG5	Intermolecular forces between water molecules are stronger than the intermolecular forces between acetone molecules. Because water includes hydrogen bonding in addition to dipole-dipole interaction.
S-MLG5	Both liquids have the same potential to pass through the gaseous phase at the same temperature, however, more number of particles of the liquid whose intermolecular force is weaker passes through the gaseous phase because the force that holds particles together is weaker.
S-NPVer5	The box representing the unit volume of liquid whose intermolecular force is weaker contains more gaseous particles. On the other hand, the box representing the unit volume of the liquid whose intermolecular force is stronger contains more gaseous particles.
Task 6	***Vapor Pressure for a System at Different Temperatures***
S-MLG6	Kinetic energy of particles increases with increasing temperature so more particles of liquid have enough energy to transfer into gaseous phase by overcoming the bonds.
S-VP6	More particles in gaseous phase on the same type of liquid of the same volume exert higher pressure on liquid surface.
S-NPVer6	There exist more gaseous particles on the liquid whose temperature is high compared to the number of gaseous particles existing on the liquid whose temperature is low.

The Mann–Whitney U test was performed on the scores from the PNM-DI and the scores from interviews on vapor pressure to identify if there was a statistically significant difference across the High PNM Understanding Group and the Low PNM Understanding Group of participants' conceptual understandings of vapor pressure.

For research question 2, the interview data were also qualitatively coded. In addition to comparing the data with scientific criteria, the participants were categorized according to representations of their level of conceptual understanding for each task.

The types of conceptual understanding levels included scientific understanding (SU), partial understanding (PU), partial understanding with alternative conception (PU/AC), alternative conception (AC), and no understanding (NU). If participants' responses included all components of scientific criteria; the correct answer with correct reason without showing any alternative conception; the conceptual understandings of these participants were categorized as *scientific understanding*. If an explanation did not include all components but some of them correct without any alternative conception, it was categorized as a *partial understanding*. The type of understanding was classified as a *partial understanding with alternative conceptions* if the responses of participants include some alternative conceptions with some scientific criteria components. It was categorized as *alternative conceptions,* if participants' responses included alternative conceptions but not any component of scientific criteria. Participants who could not make any scientific or alternative response and who did not show any type of understanding in any aspect of the task were classified as having *no understanding* of vapor pressure.

Descriptions of levels of conceptual understanding and alternative conceptions emerged from the current study can be seen in Table 3.6. Notice that Table 3.6 including the level of conceptual understanding and criteria was adopted (Abraham *et al*., 1994) but modified to reflect the current data.

Table 3.6. Level of conceptual understanding and criteria.

Level of Understanding	**Codes**	**Criteria**
Scientific understanding	SU	Includes all components of scientific criteria (identified for each aspect of the nature of vapor pressure)
Partial understanding	PU	Includes a subset of the scientific criteria components, but not all components
Partial understanding with alternative conception	PU/AC	Includes a subset of the scientific criteria components along with one or more alternative conceptions (given below)
Alternative conceptions	AC	Includes one or more alternative conceptions without clear exhibition of any components stated in scientific criteria. The alternative conceptions emerged from the data follows:
		The Nature of Vapor Pressure
	AC1	Evaporation is a result of boiling.
	AC2	Evaporation does not occur without heating.
	AC3	Evaporation does not occur at 0°C.
	AC4	Evaporation does not occur when the temperature of liquid in a system is not higher than its environment.
	AC5	Evaporation does not occur anymore when the liquid-vapor equilibrium is established.
	AC6	Evaporation rate in a closed container decreases in time.

Table 3.6. Level of conceptual understanding and criteria (cont.)

Level of Understanding	**Codes**	**Criteria**
	AC7	Evaporation rate depends on the volume of liquid; it is directly proportional to the amount of liquid.
	AC8	There is no vapor pressure in open container.
	AC9	Equilibrium is established when the reaction is completed.
	AC10	The number of total vapor particles is constant regardless of external effects applied on the system when the liquid-vapor equilibrium is established.
	AC11	Vapor pressure is the pressure exerted to only the walls of the container by gaseous particles.
	AC12	Vapor pressure is the pressure exerted by particles at vapor phase during boiling.
Alternative conceptions		*Factors Affecting Vapor Pressure*
	AC13	The amount of liquid does not affect vapor pressure if surface area is the same.
	AC14	The liquid that has higher boiling point has also greater vapor pressure.
	AC15	Vapor pressure changes when the volume of container decreases at liquid-vapor equilibrium.
	AC16	Vapor pressure is same in both open and closed containers.
	AC17	Vapor pressure increases/decreases when volume of the liquid increases/decreases.
	AC18	Vapor pressure increases if the particles are closer to each other because of greater attraction force between them.
	AC19	Vapor pressure is the same for different types of liquids if each of them is at equilibrium with their gaseous particles.
	AC20	Vapor pressure of different liquids/solutions is different during boiling.
	AC21	Vapor pressure is the same for liquids at different temperatures if each of them is at equilibrium with their gaseous particles.
	AC22	Vapor pressure occurs when the temperature changes.
	AC23	Vapor pressure only occurs before boiling starts.
No understanding	NU	Includes irrelevant or unclear evidence

4. RESULTS

In this section, the findings are presented around the research questions. The first research question examined how the participants with a high understanding of the PNM and a low understanding of the PNM compare in terms of understanding the concept of vapor pressure. The second research question investigated the level of conceptual understanding of specific vapor pressure concepts that two independent groups demonstrated. Interviews were conducted with the participants in order to answer these research questions, and the findings from the data will be provided in the following sub-sections.

4.1. Findings Related to Research Question 1

Research Question 1: *How do the groups of first-year college students with a high understanding of the PNM and a low understanding of PNM compare in terms of their understanding of vapor pressure?*

To examine the first research question, Mann Whitney U test was conducted for assessing vapor pressure scores of two independent groups that included students with a high understanding of PNM and students with a low understanding of PNM.

As shown in Table 4.1, the vapor pressure scores for the low understanding of PNM group varied from 10 to 27, and the vapor pressure scores for the high understanding of PNM group changed in between 19 and 31. Mann Whitney U test was conducted to identify if the two groups of students' conceptual understanding of vapor pressure were significantly different. The results of the Mann Whitney U test indicated that the mean ranks between the two groups (Low PNM group: 16.82; High PNM group: 32.85) were significantly different ($U = 95500$, $p < 0.01$). This result indicated that there was a statistically significant difference in the mean ranks of the two groups. Students with a high understanding of PNM had statistically significant higher vapor pressure scores than the students with a low understanding of PNM.

Table 4.1. The Mann Whitney U test of participants' scores for vapor pressure.

Groups	N	Min	Max	Mean	Sum	Mann-Whitney U	p
Low PNM	25	10	27	16.82	420.50		
High PNM	23	19	31	32.85	755.50		
Total	48					95500**	0.000

**$p < 0.01$

4.2. Findings Related to Research Question 2

Research Question 2: *What level of conceptual understanding of specific vapor pressure concepts are demonstrated by the groups of first-year college students with a high understanding of PNM and a low understanding of PNM?*

To investigate second research question, participants' level of conceptual understanding for each specific concept of vapor pressure was determined. Each task in the interviews was associated with one specific aspect of vapor pressure, namely the nature of vapor pressure, vapor pressure in containers with different volumes, vapor pressure for identical containers with different amount of liquids, vapor pressure during boiling for different liquids in open containers, vapor pressure for different liquids in identical closed containers and vapor pressure for a system at different temperatures. The following subsections presents the findings related to these aspects of vapor pressure.

4.2.1. The Nature of Vapor Pressure

The nature of vapor pressure in the interviews included three concepts involving vapor pressure, namely evaporation, boiling, and vapor pressure in a closed system.

4.2.1.1. Evaporation. Table 4.2 demonstrates the distribution of participants' level of conceptual understanding of evaporation across the high understanding of PNM and the low understanding of PNM groups.

Table 4.2. Summary of the high understanding of PNM and the low understanding of PNM participants' level of conceptual understanding of evaporation.

Level of Understanding	**High PNM**	**Low PNM**
Scientific Understanding	2 (9%)	2 (8%)
Partial Understanding	10 (43%)	10 (40%)
Partial Understanding with Alternative Conceptions	11 (48%)	13 (52%)
Alternative Conceptions	0 (0%)	0 (0%)
No Understanding	0 (0%)	0 (0%)
TOTAL	23 (100%)	25 (100%)

Based on the findings from the data on evaporation, the 2 (9%) of the participants with a high understanding of PNM indicated a scientific understanding, 10 of them (43%) held a partial understanding, and the others (48%) exhibited a partial understanding with alternative conceptions (see Table 4.2).

The following interview excerpt represents the verbal responses of a participant from the high understanding of PNM group (see Table 4.3).

Table 4.3. Interview excerpt of P 6H from the high understanding of PNM group about evaporation.

R:	…What is evaporation? Could you explain what it is, please?
P 6H:	Evaporation is turning from liquid into gas by gaining enough energy with increasing temperature when it is heated (*AC2*).
R:	What about the particles? What happens to the particles so the evaporation occurs?
P 6H:	Distance between particles increases, density decreases, intermolecular forces between particles weaken (*S-FLG1*), because of increasing distance, particles move faster and movement ability of particles increases (*S-MLG1*); they move away.

P 6H from the high understanding of PNM group was asked to define and explain the evaporation process at the submicroscopic level. P 6H provided an explanation, stating that intermolecular forces between particles weaken (*S-FLG1*), and movement ability of particles increases during evaporation (*S-MLG1*). The explanation of P 6H was in accordance with scientific criteria, but it was identified that P 6H has an alternative conception of “Heating is required for evaporation to occur” (*AC2*). Since P 6H included scientific criteria (*S-FLG1*, *S-MLG1*) with an alternative conception (*AC2*), his conceptual understanding was categorized as a *partial understanding with alternative conception* based on his interview response (see Table 3.5, Table 3.6 and Table 4.3).

Based on findings from the data on evaporation for the low understanding of PNM group, 2 participants (8%) showed a scientific understanding, 10 of them (40%) exhibited a partial understanding, and the others (52%) held a partial understanding with alternative conceptions (see Table 4.2).

The following interview excerpt represents the verbal responses of a participant from the low understanding of PNM group (see Table 4.4).

Table 4.4. Interview excerpt of P 8L from the low understanding of PNM group about evaporation.

R:	…What is evaporation? Could you explain what it is, please?
P 8L:	Evaporation is the expansion of molecules in liquid phase; that is the expansion of water by gaining energy as heat, this means increasing the distance between molecules.
R:	What do you mean by “expansion”?
P 8L:	Intermolecular forces between molecules weakens, they are broken, so distance between molecules increases. In this way, its state changes from liquid to gas.
R:	What happens at submicroscopic level during evaporation?
P 8L:	Evaporation is a change in state; it changes from liquid to gas. Distance between molecules increases at the submicroscopic level.
R:	What about the particles? What happens to the particles, so the evaporation occurs?
P 8L:	What happens to the particles?, Do their bonds break?, No; it would be a chemical change if it was. The intermolecular forces between molecules weaken (*S-FLG1*) by gaining energy as heat (*AC2*), molecules are the same, and their movement ability increases (*S-MLG1*).

P 8L from the low understanding of group was asked to define and explain the evaporation process at the submicroscopic level. P 8L explained intermolecular forces between particles weaken (*S-FLG1*) and movement ability of the particles increases via evaporation. P 8L explained evaporation in a scientific manner, but it was revealed that P 8L has an alternative conception of “Heating is required for evaporation to occur” (*AC2*). P

8L also misused the word of “expansion” while describing evaporation. Since P 8L included scientific criteria (*S-FLG1*, *S-MLG1*) with an alternative conception (*AC2*), conceptual understanding of P 8L was categorized as a *partial understanding with alternative conception* on the interview (see Table 3.5, Table 3.6 and Table 4.4).

4.2.1.2. Boiling. Table 4.5 demonstrates the distribution of participants’ level of conceptual understanding of boiling across the high understanding of PNM and the low understanding of PNM groups.

Table 4.5. Summary of the high understanding of PNM and the low understanding of PNM participants’ level of conceptual understanding of boiling.

Level of Understanding	**High PNM**	**Low PNM**
Scientific Understanding	5 (22%)	2 (8%)
Partial Understanding	17 (74%)	22 (88%)
Partial Understanding with Alternative Conception	0 (0%)	0 (0%)
Alternative Conceptions	0 (0%)	0 (0%)
No Understanding	1 (4%)	1 (4%)
TOTAL	23 (100%)	25 (100%)

Based on the findings from the data on boiling for the high understanding of PNM group, 5 participants (22%) indicated a scientific understanding, 17 of them (74%) held a partial understanding, and the others (4%) exhibited a partial understanding with alternative conceptions (see Table 4.5).

Table 4.6. Interview excerpt of P 36H from the high understanding of PNM group about boiling.

R:	…What is boiling? Could you explain what it is, please?
P 36H:	When the vapor pressure equals to the atmospheric pressure (*S-AP1*), bubbles occur on the surface and inside of a liquid. This is boiling.
R:	Could you explain what happens during boiling at the submicroscopic level?
P 36H:	Evaporation occurs at everywhere of the liquid at the same time during boiling, distance between molecules increases, and their movement ability increases (*S-MLG1*), so they turn from liquid into gas.

The interview excerpt given at Table 4.6 represents the verbal responses of a participant from the high understanding of PNM group.

P 36H from the high understanding of PNM group was asked to define and explain boiling at the submicroscopic level. P 36H provided an explanation in accordance with scientific criteria without any alternative conception, but it was not adequate for scientific understanding. P 36H explained that boiling starts when the vapor pressure of a substance equals to the atmospheric pressure (*S-AP1*), and the movement ability of particles increases via boiling (*S-MLG1*). Although P 36H included two of the scientific criteria (*S-AP1*, *S-MLG1*) in his explanation, P 36H did not mention about the third scientific criteria "intermolecular forces between particles" (*S-FLG1*), so conceptual understanding of P 36H was categorized as a *partial understanding* on the interview (see Table 3.5, Table 3.6 and Table 4.6).

Based on the findings from the data on boiling for the low understanding of PNM group, 2 participants (8%) showed a scientific understanding, 22 of them (88%) exhibited a partial understanding, and the others (4%) held a partial understanding with alternative conceptions (see Table 4.5).

The following interview excerpt represents the verbal responses of a participant from the low understanding of PNM group (see Table 4.7).

Table 4.7. Interview excerpt of P 31L from the low understanding of PNM group about boiling.

R:	…What is boiling? Could you explain what it is, please?
P 31L:	It is having enough energy to turn from liquid to gas, bubbles occur during boiling. Evaporation is the result of boiling (*AC1*).
R:	Could you explain what happens during boiling at the submicroscopic level?
P 31L:	Distance between molecules increases, movement ability of particles increases (*S-MLG1*) due to increasing energy.

P 31L from the low understanding of PNM group was asked to define and explain boiling at the submicroscopic level. The explanation of P 31L did not indicate a scientific understanding. P 31L explained that the movement ability of particles increases via boiling

(*S-MLG1*), but she did not mention the scientific criteria of "atmospheric pressure" (*S-AP1*) and "intermolecular forces between particles" (*S-FLG1*). In addition, an alternative conception of "Evaporation is the result of boiling" was detected. So conceptual understanding of P 31L was categorized as a *partial understanding with alternative conceptions* on the interview (see Table 3.5, Table 3.6 and Table 4.7).

<u>4.2.1.3. Vapor Pressure.</u> Table 4.8 shows the distribution of participants' level of conceptual understanding of vapor pressure across the high understanding of PNM and the low understanding of PNM groups.

Table 4.8. Summary of the high understanding of PNM and the low understanding of PNM participants' level of conceptual understanding of vapor pressure.

Level of Understanding	**High PNM**	**Low PNM**
Scientific Understanding	14 (61%)	6 (24%)
Partial Understanding	1 (4%)	1 (4%)
Partial Understanding with Alternative Conception	8 (35%)	18 (72%)
Alternative Conceptions	0 (0%)	0 (0%)
No Understanding	0 (0%)	0 (0%)
TOTAL	23 (100%)	25 (100%)

Based on the findings from the data on vapor pressure for the high understanding of PNM group, 14 participants (61%) indicated a scientific understanding, 1 of them (4%) held a partial understanding, and the others (35%) exhibited a partial understanding with alternative conceptions (see Table 4.8).

Table 4.9. Interview excerpt of P 26H from the high understanding of PNM group about vapor pressure.

R:	…What is pressure? Could you explain what it means at the submicroscopic level?
P 26H:	Pressure is the sum of forces applied by molecules.
R:	Could you explain more?
P 26H:	Every molecule applies force to around, to the container, with its mass, they make collisions, move and exert force by their mass. Pressure is the sum of all applied force with the collisions.

Table 4.9. Interview excerpt of P 26H from the high understanding of PNM group about vapor pressure (cont.)

R:	Could you explain what equilibrium means at the submicroscopic level?
P 26H:	Equilibrium is two-sided. If we make any change on a side, a change on the other side occurs, too. We say equilibrium shifted toward forward or backward. If any change does not occur, both forward and reverse reaction continues to occur at the same rate at equilibrium (*S-Eq*).
R:	Could you explain what vapor pressure means at the submicroscopic level?
P 26H:	Gas pressure of a liquid applied on atmospheric pressure depending on temperature (*AC22*).
R:	Could you explain more?
P 26H:	Speed of molecules changes with changing temperature, the number of collisions and applied force changes depending on temperature, so vapor pressure is the force applied by vapor molecules at gaseous phase when they collide around.

The interview excerpt given at Table 4.9 represents the verbal responses of a participant from the high understanding of PNM group.

P 26H from the high understanding of PNM group was asked to define and explain vapor pressure at the submicroscopic level. P 26H provided an explanation of “equilibrium” in a scientific manner, but he could not explain vapor pressure in accordance with the scientific criteria because of the insufficiently explaining the equilibrium between liquid and vapor while describing vapor pressure in a closed container. P 26H included the criterion of “equilibrium” (*S-Eq*) in his explanation with an alternative conception of vapor pressure changes when the temperature changes *(AC22)*, so conceptual understanding of P 26H was categorized as a *partial understanding with alternative conception* on the interview (see Table 3.5, Table 3.6 and Table 4.9).

Based on the findings from the data on vapor pressure for the low understanding of PNM, 6 participants (24%) showed a scientific understanding, 1 of them (4%) exhibited a partial understanding, and the others (72%) held a partial understanding with alternative conceptions (see Table 4.8).

The following interview excerpt represents the verbal responses of a participant from the low understanding of PNM group (see Table 4.10).

Table 4.10. Interview excerpt of P 5L from the low understanding of PNM group about vapor pressure.

R:	…What is pressure? Could you explain what it means at the submicroscopic level?
P 5L:	Pressure is the total force applied by molecules.
R:	Could you explain what equilibrium means at the submicroscopic level?
P 5L:	Equilibrium occurs when the reaction is completed, everything is finished, and we say there is equilibrium if there is no change anymore (*AC9*).
R:	Could you explain what vapor pressure means at submicroscopic level?
P 5L:	Vapor pressure is directly proportional to boiling point (*AC14*); vapor pressure is higher if the boiling point is higher. Vapor pressure only occurs when the atmospheric pressure is higher than the liquid pressure. This is before boiling starts (*AC23*).
R:	Could you explain more at the submicroscopic level?
P 5L:	It is the total force applied by evaporated molecules when they collide around before boiling.

P 5L from the low understanding of PNM group was asked to define and explain vapor pressure at the submicroscopic level. P 5L could not provide an explanation of "equilibrium" in a scientific manner; an alternative conception of "Equilibrium occurs when the reaction is completed" (*AC9*) was detected while analyzing the "equilibrium" criterion. In addition, P 5L could not explain "vapor pressure" in accordance with scientific criteria; alternative conceptions of "The liquid that has higher boiling point has also greater vapor pressure" (*AC14*) and "Vapor pressure only occurs before boiling starts" (*AC23*) were noticed. P 5L included alternative conceptions to the explanation; so conceptual understanding of P 5L was categorized as *alternative conceptions* on the interview (see Table 3.5, Table 3.6 and Table 4.10).

4.2.2. Vapor Pressure in Containers with Different Volumes

A task on the interview focuses on comparing vapor pressure in containers with different volumes. Table 4.11 demonstrates the distribution of participants' level of conceptual understanding on this task across the high understanding of PNM and the low understanding of PNM groups.

Table 4.11. Summary of the high understanding of PNM and the low understanding of PNM participants' level of conceptual understanding of vapor pressure in containers with different volumes.

Level of Understanding	**High PNM**	**Low PNM**
Scientific Understanding	6 (26%)	4 (16%)
Partial Understanding	2 (9%)	0 (0%)
Partial Understanding with Alternative Conception	7 (30%)	3 (12%)
Alternative Conceptions	7 (30%)	18 (72%)
No Understanding	1 (5%)	0 (0%)
TOTAL	23 (100%)	25 (100%)

Based on the findings from the data on this task for high understanding of PNM group, 6 participants (26%) indicated a scientific understanding, 2 of them (9%) held a partial understanding, 7 of them (30%) showed a partial understanding with alternative conceptions, 7 of them (30%) had alternative conceptions, and the others (5%) exhibited no understanding (see Table 4.11).

Table 4.12. Interview excerpt of P 18H from the high understanding of PNM group about vapor pressure in containers with different volumes.

R: There is some water in a closed container, and the liquid-vapor equilibrium is established at 25^{o}C. Volume of the container is decreased so that the volume of vapor becomes half. If we observe the unit volume of water and vapor at the submicroscopic level, what would we see? Could you explain by drawing?

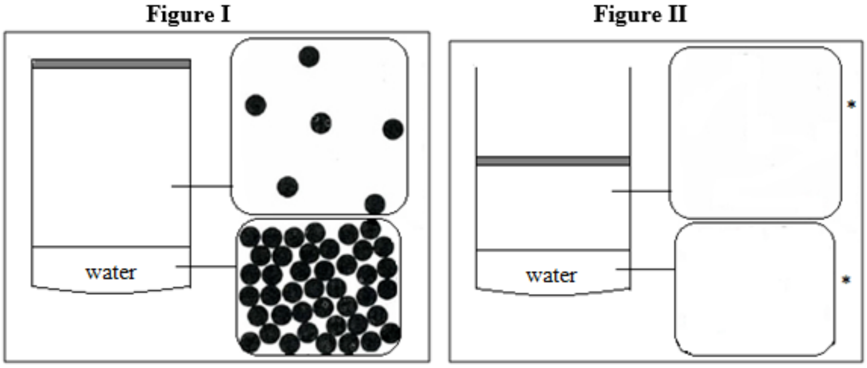


Table 4.12. Interview excerpt of P 18H from the high understanding of PNM group about vapor pressure in containers with different volumes (cont.)

P 18H:	I will draw the same number of particles in a unit volume (*S-NPVis1*). Number of particles in a unit volume will be the same (*S-NPVer1*). However, some vapor will turn to liquid. Although there is the same number of particles in a unit volume, total number of particles in gas phase decreases. The system will arrange the volume to establish the equilibrium again while vapor turns to liquid (S-Eq2).
R:	Why do you think there will be so?
P 18H:	Vapor pressure is related to the number of particles at a unit volume, and the number of particles per unit volume will be the same, so nothing will change for vapor pressure.
R:	How does the vapor pressure change when the volume of container is decreased so that the volume of vapor becomes half?
P 18H:	Because vapor pressure will be directly proportional to the number of gaseous particles at unit volume, the final pressure will be the same as the initial (*S-VP2*). Because an equilibrium will be established again.

The interview excerpt given at Table 4.12 represents the verbal responses of a participant from the high understanding of PNM group.

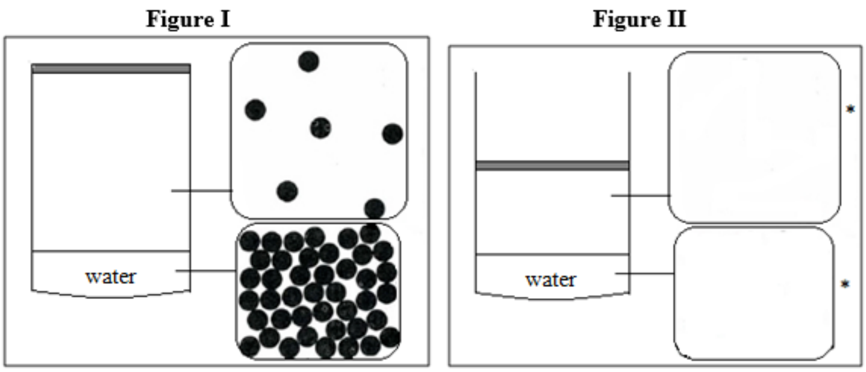
P 18H from the high understanding of PNM group was asked to compare vapor pressure in two containers with different volumes. P 18H drew and explained that the number of particles at a unit volume is the same because of established equilibrium; therefore, vapor pressure does not change. The provided explanation of P 18H was in accordance with all four scientific criteria (*S-NPVis1*, *S-NPVer1*, *S-Eq2*, *S-VP2*), so conceptual understanding of P 18H was categorized as a *scientific understanding* on the interview (see Table 3.5, Table 3.6, and Table 4.12).

Based on the findings from the data on this task for the low understanding of PNM group, 4 participants (16%) showed a scientific understanding, 3 of them (12%) exhibited a partial understanding with alternative conceptions, and the others (72%) held alternative conceptions (see Table 4.11).

The following interview excerpt represents the verbal responses of a participant from the low understanding of PNM group (see Table 4.13).

Table 4.13. Interview excerpt of P 28L from the low understanding of PNM group about vapor pressure in containers with different volumes.

R:	There is some water in a closed container, and the liquid-vapor equilibrium is established at 25°C. Volume of the container is decreased so that the volume of vapor becomes half. If we observe the unit volume of water and vapor at the submicroscopic level, what would we see? Could you explain by drawing?



P 28L:	The number of particles at liquid phase is the same. The number of particles at gaseous phase changes, the number of molecules at gaseous phase is more.
R:	Why do you think there will be so?
P 28L:	When the piston moves down, the vapor volume becomes half, and the distance between gaseous molecules decreases, this means there will be more gaseous molecules in a small volume (*AC10*).
R:	How does the vapor pressure change when the volume of container is decreased, so that the volume of vapor becomes half?
P 28L:	Vapor pressure of water increases.
R:	Could you explain more at the submicroscopic level?
P 28L:	I think so because the density of gas molecules increases. The volume occupied by gas molecules decreased when the piston moves down, but the number of gas molecules does not change. So there are more collisions in a unit volume, and the vapor pressure increases.

P 28L from the low understanding of PNM group was asked to compare vapor pressure in two containers with different volumes. P 28L could not included “equilibrium” into the explanation; instead, P 28L explained that gas is compressed in Figure II. The alternative conception of “Number of total vapor particles is constant regardless of external effects applied on the system when the liquid-vapor equilibrium is established” (*AC10*) was detected. Thus, P 28L could not provide an explanation about the dimensions of scientific criteria including “number of particles”, “equilibrium” and “vapor pressure”; so conceptual understanding of P 28L was categorized as *alternative conceptions* on the interview (see Table 3.5, Table 3.6, and Table 4.13).

4.2.3. Vapor Pressure for Containers with Different Amount of Liquids

A task on the interview focuses on comparing vapor pressure for containers with different amount of liquids. Table 4.14 exhibits the distribution of participants' level of conceptual understanding on this task across the high understanding of PNM and the low understanding of PNM groups.

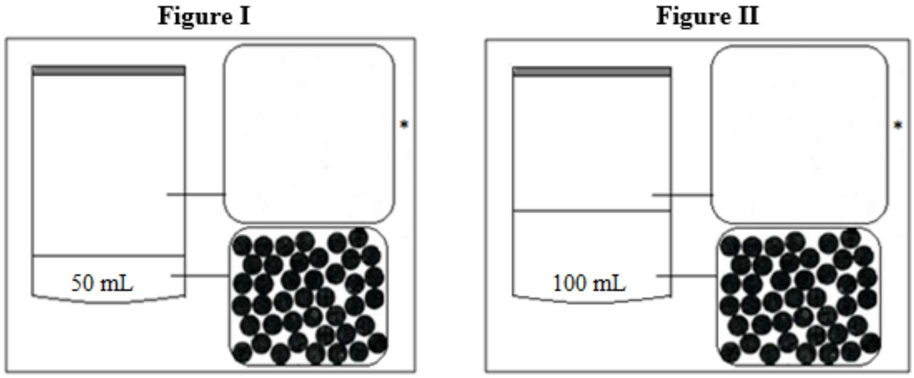
Table 4.14. Summary of the high understanding of PNM and the low understanding of PNM participants' level of conceptual understanding of vapor pressure for containers with different amount of liquids.

Level of Understanding	**High PNM**	**Low PNM**
Scientific Understanding	6 (26%)	1 (4%)
Partial Understanding	1 (5%)	3 (12%)
Partial Understanding with Alternative Conception	4 (17%)	3 (12%)
Alternative Conceptions	12 (52%)	18 (72%)
No Understanding	0 (0%)	0 (0%)
TOTAL	23 (100%)	25 (100%)

Based on the findings from the data on this task for the high understanding of PNM group, 6 participants (26%) indicated a scientific understanding, 1 of them (5%) held a partial understanding, 4 of them (17%) showed a partial understanding with alternative conceptions, and the others (52%) exhibited alternative conceptions (see Table 4.14).

The following interview excerpt represents the verbal responses of a participant from the high understanding of PNM group (see Table 4.15).

Table 4.15. Interview excerpt of P 40H from the high understanding of PNM group about vapor pressure for containers with different amount of liquids.

R:	There are 50 mL and 100 mL of water at different identical containers. Liquid-vapor equilibrium is established at both containers at 25°C. If we could observe the unit volume of vapor for both containers, what would we see? Could you explain by drawing, please?
	
P 40H:	There is more vapor particles in Figure I, and there is less vapor particles in Figure II.
R:	Why do you think so?
P 40H:	The volumes of containers are the same. Pressure increases with decreasing volume, because of PV=nRT. The container with 50 mL of water has less volume of liquid, then the pressure is higher, and therefore more gas molecules will be in a unit volume.
R:	Do you mean by the volume of a liquid while saying "the pressure is higher because of the decreasing volume"?
P 40H:	Yes. Because vapor pressure is inversely proportional to the volume of a liquid (*AC17*).
R:	So you mean there is a relationship between vapor pressure and the volume of a liquid?
P 40H:	Yes.
R:	What about vapor pressure? Could you compare the vapor pressure of these two systems, please?
P 40H:	Vapor pressure in a container with 50 mL of water is higher than the container with 100 mL of water.
R:	Why do you think so? Could you explain at the submicroscopic level?
P 40H:	There are more molecules in a unit volume, they collide more and exert higher pressure in total.

P 40H from the high understanding of PNM group was asked to compare the vapor pressure for containers with different amount of liquids. P 40H could not provided an explanation of "number of particles" (S-NPVis3, S-NPVer3), "equilibrium" (S-Eq3) and "vapor pressure" (S-VP3) in accordance with scientific criteria. P 40H used ideal gas law to compare the vapor pressures for containers with different amount of liquids, but P 40H misused the formula because P 40H accepted the volume in the formula is the volume of the liquid. In addition, the alternative conception of "Vapor pressure is inversely proportional to the volume of a liquid" (AC17) was identified so conceptual understanding of P 40H was categorized as *alternative conceptions* on the interview (see Table 3.5; Table 3.6, and Table 4.15).

Based on the findings from the data on this task for the low understanding of PNM group, 1 participant (4%) showed a scientific understanding, 3 of them (12%) had a partial understanding, 3 of them (12%) exhibited a partial understanding with alternative conceptions, and the others (72%) held alternative conceptions (see Table 4.14).

The interview excerpt given below represents the verbal responses of a participant from the low understanding of PNM group (see Table 4.16).

Table 4.16. Interview excerpt of P 29L from the low understanding of PNM group about vapor pressure for containers with different amount of liquids.

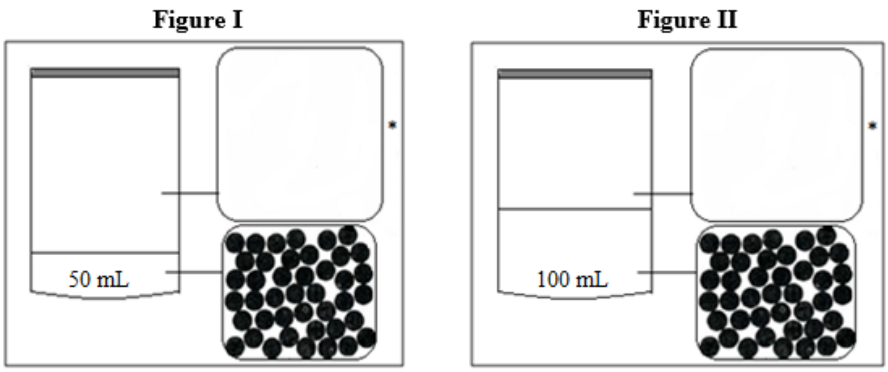
R:	There are 50 mL and 100 mL of water at different identical containers. Liquid-vapor equilibrium is established at both containers at 25°C. If we could observe the unit volume of vapor for both containers, what would we see? Could you explain by drawing, please? 
P 29L:	I draw more particles in Figure II; there are more particles in a unit volume of the container in Figure II.
R:	Why do you think so?
P 29L:	Volume of water is higher in Figure II. Evaporation depends on the amount of liquid (*AC7*), let's say 10% of liquid volume evaporates, then 5 mL of 50 mL evaporates in Figure I and 10 mL of 100 mL evaporates in Figure II, the number of gas molecules changes according to this reasoning.

Table 4.16. Interview excerpt of P 29L from the low understanding of PNM group about vapor pressure for containers with different amount of liquids (cont.)

R:	What about vapor pressure? Could you compare the vapor pressure of these two systems, please?
P 29L:	Vapor pressure in the container with 100 mL of water is higher than the container with 50 mL of water.
P 29L:	The number of gas molecules is higher in the container with 100 mL of water even if the volume of gas is less. More gas molecules mean more force so higher vapor pressure.
R:	Do you think vapor pressure is affected by the amount of liquid?
P 29L:	Yes (*AC17*).

P 29L from the low understanding of PNM group was asked to compare vapor pressure for containers with different amount of liquids. P 29L's explanation was not in accordance with scientific criteria of *S-NPVis3*, *S-NPVer3*, *S-Eq3* and *S-VP3*; representing "number of particles visually and verbally", "equilibrium" and "vapor pressure" respectively. In addition, alternative conceptions of "Evaporation depends on the amount of liquid" (*AC7*) and "The volume of the liquid affects vapor pressure" (*AC17*) were identified; so conceptual understanding of P 29L was categorized as *alternative conceptions* on the interview (see Table 3.5, Table 3.6 and Table 4.16).

4.2.4. Vapor Pressure for Different Liquids in Open Containers

A task on the interview focuses on comparing vapor pressure for different liquids in open containers during boiling. Table 4.17 indicates the distribution of participants' level of conceptual understanding on this task across the high understanding of PNM and the low understanding of PNM groups.

Table 4.17. Summary of the high understanding of PNM and the low understanding of PNM participants' level of conceptual understanding of vapor pressure for different liquids in open containers.

Level of Understanding	**High PNM**	**Low PNM**
Scientific Understanding	0 (0%)	0 (0%)
Partial Understanding	15 (65%)	5 (20%)
Partial Understanding with Alternative Conception	2 (9%)	4 (16%)
Alternative Conceptions	6 (26%)	13 (52%)
No Understanding	0 (0%)	3 (12%)
TOTAL	23 (100%)	25 (100%)

Based on the findings from the data on this task for the high understanding of PNM group, none of the participants (0%) indicated a scientific understanding, 15 of them (65%) held a partial understanding, 2 of them (9%) showed a partial understanding with alternative conceptions, and the others (26%) exhibited alternative conceptions (see Table 4.17).

The following interview excerpt represents the verbal responses of a participant from the high understanding of PNM group (see Table 4.18).

Table 4.18. Interview excerpt of P 11H from the high understanding of PNM group about the vapor pressure of different liquids in open containers.

R:	100 mL of water, 100 mL of ethyl alcohol, and 100 mL of salty water whose percentage by mass is 15% are in different open identical containers. Could you compare the vapor pressure of these systems during boiling?

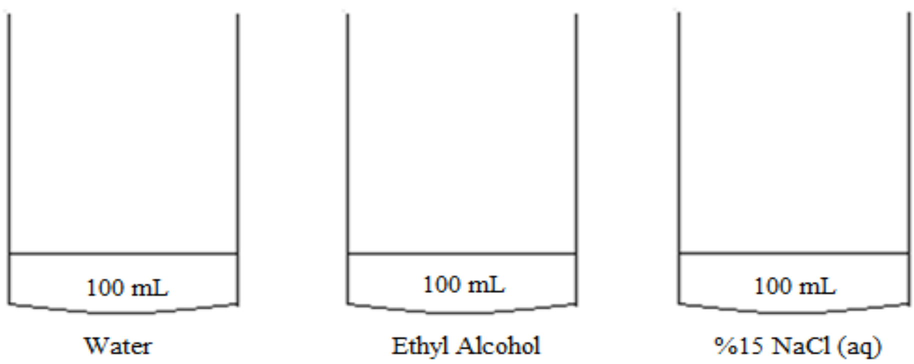


Table 4.18. Interview excerpt of P 11H from the high understanding of PNM group about the vapor pressure of different liquids in open containers (cont.)

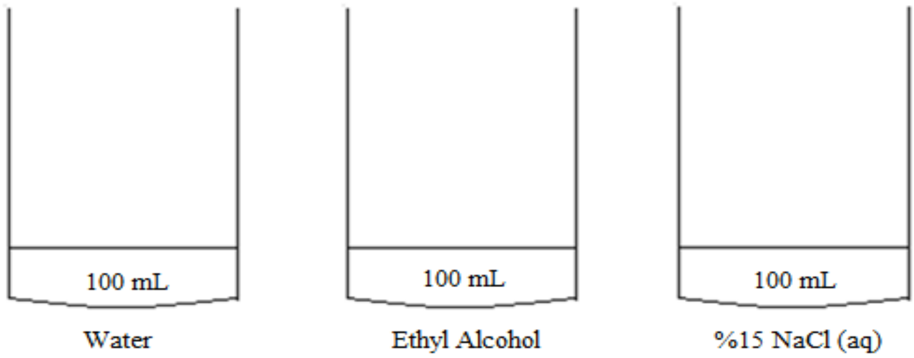
P 11H:	If all of them are boiling, so vapor pressures are the same during boiling.
R:	Why do you think so? Could you explain at the submicroscopic level?
P 11H:	Alcohol boils earlier than the others, because its intermolecular forces are weaker. Water has hydrogen bonding between molecules as intermolecular force so its boiling point is higher than alcohol. So alcohol boils first, then water, and then salty water boils last. Boiling occurs when the inner pressure equals to the atmospheric pressure. If all of them are boiling, inner pressure of all systems equals to the same atmospheric pressure (*S-AP4*), so vapor pressure of all systems are the same (*S-VP4*).

P 11H from the high understanding of PNM group was asked to compare vapor pressure for different liquids in open containers. P 11H provided an explanation in accordance with scientific criteria of "air pressure" (*S-AP4*) and "vapor pressure" without any alternative conception, but it did not indicate the scientific understanding. Because P 11H did not mention "the number of gaseous particles on liquid during boiling" (*S-NPVer4*) and "the change in movement ability of particles when boiling occurred" (*S-MLG4*) although "intermolecular forces" were included in the explanation. So conceptual understanding of P 11H was categorized as a *partial understanding* on the interview (see Table 3.5, Table 3.6 and Table 4.18).

Based on the findings from the data on this task for the low understanding of PNM group, none of the participants (0%) showed a scientific understanding, 5 of them (20%) had a partial understanding, 4 of them (16%) exhibited a partial understanding with alternative conceptions, 13 of them (52%) indicated alternative conceptions, and the others (12%) held no understanding (Table 4.17).

The following interview excerpt represents the verbal responses of a participant from the low understanding of PNM group (see Table 4.19).

Table 4.19. Interview excerpt of P 21L from the low understanding of PNM group about vapor pressure for different liquids in open container.

R:	100 mL of water, 100 mL of ethyl alcohol, and 100 mL of salty water, whose percentage by mass is 15%, are in different open identical containers. Could you compare the vapor pressure of these systems during boiling? 
P 21L:	All of them are boiling but it does not change the vapor pressure (*AC20*). Vapor pressure is the most for the liquid that is more volatile, because more molecules evaporate. Because of this reason, the vapor pressure of ethyl alcohol is higher than the others, then the water, and then salty water.
R:	Why do you think so? Could you explain at the submicroscopic level?
P 21L:	Substances have different molecular structures. The most volatile one has the highest vapor pressure. The substance, that has the weakest intermolecular force, is the most volatile. In this case, ethyl alcohol is the most volatile substance, and I expect it has the highest vapor pressure.

P 21L from the low understanding of PNM group was asked to compare the vapor pressure for different liquids in open containers. P 21L's explanation was not in accordance with scientific criteria of S-NPVer4, S-AP4, S-VP4 and S-MLG4; representing "the number of particles", "air pressure", "vapor pressure" and "the change in movement ability of particles when boiling occurred", respectively. In addition, the explanation indicated an alternative conception that vapor pressure of different liquids/solutions is different during boiling; so conceptual understanding of P 21L was categorized as *alternative conceptions* on the interview (see Table 3.5, Table 3.6 and Table 4.19).

4.2.5. Vapor Pressure for Different Liquids in Closed Containers

A task on the interview focuses on comparing vapor pressure for different liquids in closed containers. Table 4.20 demonstrates the distribution of participants' level of conceptual understanding on this task across the high understanding of PNM and the low understanding of PNM groups.

Table 4.20. Summary of the high understanding of PNM and the low understanding of PNM participants' level of conceptual understanding of vapor pressure for different liquids in closed containers.

Level of Understanding	High PNM	Low PNM
Scientific Understanding	3 (13%)	0 (0%)
Partial Understanding	18 (79%)	16 (64%)
Partial Understanding with Alternative Conception	1 (4%)	4 (16%)
Alternative Conceptions	1 (4%)	3 (12%)
No Understanding	0 (0%)	2 (8%)
TOTAL	23 (100%)	25 (100%)

Based on the findings from the data on this task for the high understanding of PNM group, 3 of the participants (13%) indicated a scientific understanding, 18 of them (79%) held a partial understanding, 1 of them (4%) showed a partial understanding with alternative conceptions, and the others (4%) exhibited alternative conceptions (see Table 4.20).

Table 4.21. Interview excerpt of P 48H from the high understanding of PNM group about vapor pressure for different liquids in closed containers.

R: 100 mL of water and 100 mL of acetone are in different closed identical containers. Liquid-vapor equilibrium is established at 25°C. If we observe the unit volume of vapor at the submicroscopic level, what would we see? Could you explain by drawing?

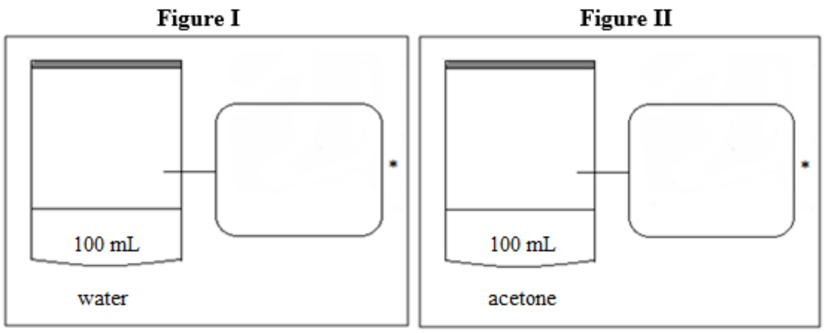


Table 4.21. Interview excerpt of P 48H from the high understanding of PNM group about vapor pressure for different liquids in closed containers (cont.)

P 48H:	I draw fewer particles in Figure I (*S-NPVis5*), there are fewer particles in a unit volume of the container with water, and there are more particles in a unit volume of the container with acetone (*S-NPVer5*).
R:	Why do you think so?
P 48H:	Water and acetone have different boiling points, different volatility, so their evaporation rate at 25^{o}C is different.
R:	Why?
P 48H:	Because there is hydrogen bonding between water molecules, but there is no hydrogen bonding between acetone molecules. More acetone molecules evaporate by the same amount of energy (*S-MLG5*), because its intermolecular forces are weaker than water (*S-FLG5*).
R:	Could you compare the vapor pressure of these systems?
P 48H:	Acetone has higher vapor pressure.
R:	Could you explain at the submicroscopic level?
P 48H:	Because there are more acetone molecules at the same unit volume, so there are more collisions, and acetone molecules exert more pressure in total.

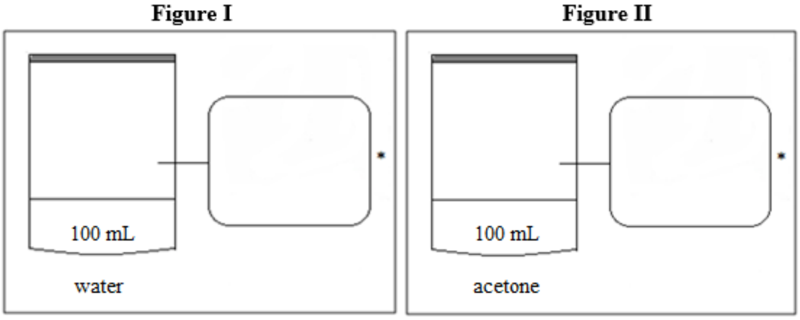
The interview excerpt given at Table 4.21 represents the verbal responses of a participant from the high understanding of PNM group.

P 48H from the high understanding of PNM group was asked to compare the vapor pressure for different liquids in closed containers. P 48H provided an explanation in accordance with all scientific criteria without any alternative conception. P 48H explained that intermolecular forces between acetone molecules are weaker than water (*S-FLG5*), so the number of evaporated molecules by the same amount of energy is higher than water (*S-MLG5*), there is more molecules in a unit volume in Figure II (*S-NPVer5 S-NPVis5*) in a scientific manner. So conceptual understanding of P 48H was categorized as a *scientific understanding* on the interview (see Table 3.5, Table 3.6, and Table 4.21).

Based on the findings from the data on this task for the low understanding of PNM group, none of the participants (0%) showed a scientific understanding, 16 of them (64%) had a partial understanding, 4 of them (16%) exhibited a partial understanding with alternative conceptions, 3 of them (12%) indicated alternative conceptions, and the others (8%) held no understanding (see Table 4.20).

The following interview excerpt represents the verbal responses of a participant from the low understanding of PNM group (see Table 4.22).

Table 4.22. Interview excerpt of P 43L from the low understanding of PNM group about vapor pressure for different liquids in closed container.

R:	100 mL of water and 100 mL of acetone are in different closed identical containers. Liquid-vapor equilibrium is established at 25°C. If we observe the unit volume of vapor at the submicroscopic level, what would we see? Could you explain by drawing?
	Figure I **Figure II** 
P 43L:	I draw more particles in Figure II (*S-NPVis5*), acetone is more volatile, so there are more particles at a unit volume of the container with acetone in Figure II (*S-NPVer5*).
R:	Why do you think so?
P 43L:	Acetone is more volatile, so it evaporates easily.
R:	Why is acetone more volatile?
P 43L:	Intermolecular forces between acetone molecules are weaker, there is hydrogen bonding between water molecules, and it is a strong type of intermolecular force (*S-FLG5*).
R:	Could you compare the vapor pressure of these systems?
P 43L:	Vapor pressure of acetone is higher.
R:	Why do you think so?
P 43L:	Evaporation rate is higher, the number of gas molecules is more, and so the pressure exerted by gas molecules is higher when compared to water. Boiling point of acetone is lower, so its vapor pressure is higher.

P 43L from the low understanding of PNM group was asked to compare vapor pressure for different liquids in closed container. P 43L's explanation was in accordance with scientific criteria without any alternative conception. P 43L explained there are more gaseous particles in Figure II (S-NPVis5, S-NPVer5) because of weaker intermolecular force (S-FLG5) in a scientific manner, but could not explained "more number of particles of the liquid whose intermolecular force is weaker passes through gaseous phase by the same amount of energy" explicitly. So conceptual understanding of P 43L was categorized as a *partial understanding* on the interview (see Table 3.5, Table 3.6, and Table 4.22).

4.2.6. Vapor Pressure for a System at Different Temperatures

A task on the interview focuses on comparing vapor pressure for a system at different temperatures. Table 4.23 demonstrates the distribution of participants' level of conceptual understanding on this task across the high understanding of PNM and the low understanding of PNM groups.

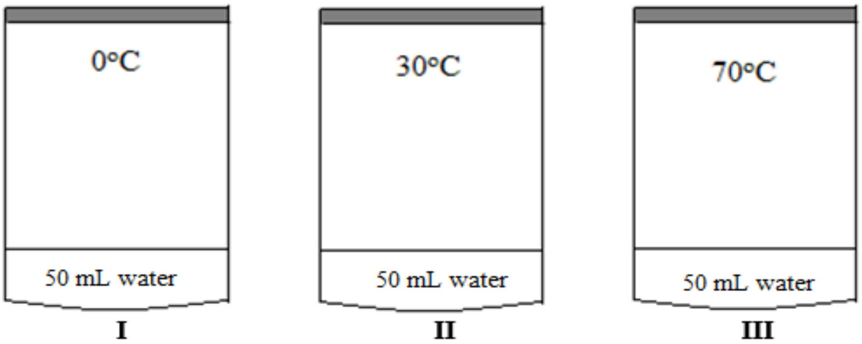
Table 4.23. Summary of the high understanding of PNM and the low understanding of PNM participants' level of conceptual understanding of vapor pressure for a system at different temperatures.

Level of Understanding	**High PNM**	**Low PNM**
Scientific Understanding	4 (17%)	7 (28%)
Partial Understanding	19 (83%)	16 (64%)
Partial Understanding with Alternative Conception	0 (0%)	1 (4%)
Alternative Conceptions	0 (0%)	0 (0%)
No Understanding	0 (0%)	1 (4%)
TOTAL	23 (100%)	25 (100%)

Based on the findings from the data on this task for the high understanding of PNM group, 4 of the participants (17%) indicated a scientific understanding, and the others (83%) held a partial understanding (see Table 4.23).

The following interview excerpt represents the verbal responses of a participant from the high understanding of PNM group (see Table 4.24).

Table 4.24. Interview excerpt of P 4H from the high understanding of PNM group about vapor pressure for a system at different temperatures.

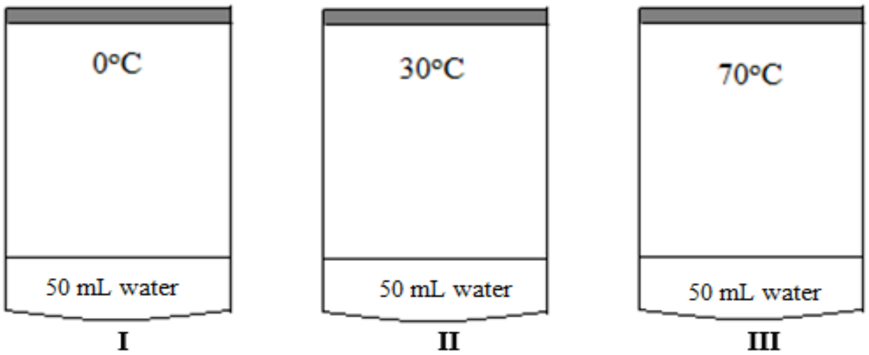
R:	There are three identical closed containers, and each of them contains 50 mL of water at different temperatures that are 0^oC, 30^oC and 70^oC. Could you compare the vapor pressure of these systems?
	
P 4H:	I expect more liquid water molecules evaporate by overcoming the bonds with increasing temperature (*S-MLG6*), equilibrium will be established again after evaporation. Water at 70^oC evaporates more because of increasing kinetic energy; there are more molecules at gas phase on the liquid whose temperature is higher (*S-NPVer6*).
R:	Could you compare the vapor pressure?
P 4H:	More molecules at gas phase means higher vapor pressure; so water at 70^oC has the highest vapor pressure, and water at 0^oC has the lowest vapor pressure (*S-VP6*).
R:	How could you do this order?
P 4H:	I compared the number of gas particles on liquid for each system. If there are more gas molecules on the liquid, there is higher vapor pressure.

P 4H from the high understanding of PNM group was asked to compare vapor pressure for a system at different temperatures. P 4H's explanation was in accordance with scientific criteria without any alternative conceptions. P 4H explained that there exist more gas particles on the liquid whose temperature is higher (*S_NPVer6*) because it evaporates easier due to increasing kinetic energy, so the vapor pressure of water at 70^oC is the highest, whereas the vapor pressure of water at 0^oC is the lowest. So conceptual understanding of P 4H was categorized as a *scientific understanding* on the interview (see Table 3.5, Table 3.6, and Table 4.24).

Based on the findings from the data on this task for the low understanding of PNM group, 7 of the participants (28%) showed a scientific understanding, 16 of them (64%) had a partial understanding, 1 of them (16%) exhibited a partial understanding with alternative conceptions, and the others (4%) indicated no understanding (see Table 4.23).

The following interview excerpt represents the verbal responses of a participant from the low understanding of PNM group (see Table 4.25).

Table 4.25. Interview excerpt of P 25L from the low understanding of PNM group about vapor pressure for a system at different temperatures.

R:	There are three identical closed containers, and each of them contains 50 mL of water at different temperatures that are 0°C, 30°C and 70°C. Could you compare the vapor pressure of these systems?
	
P 25L:	Vapor pressure of water at 70°C is the highest, and vapor pressure of water at 0°C is the lowest.
R:	Could you explain why you think so?
P 25L:	Water freezes at 0°C; so vapor pressure is minimum at 0°C. Boiling occurs at 100°C and vapor pressure increases by increasing temperature. Therefore, water at 70°C has the higher vapor pressure, and water at 0°C has the lower vapor pressure.
R:	Could you explain more at the submicroscopic level?
P 25L:	When the temperature increases, the rate of evaporation increases, and the number of molecules at gas phase increases (*S-NPVer6*), the number of collisions increases, and so the exerted pressure on liquid surface increases (*S-VP6*).

P 25L from the low understanding of PNM group was asked to compare vapor pressure for a system at different temperatures. P 25L provided an explanation in accordance with some scientific criteria without any alternative conception, P 25L explained that the number of gas molecules increases with increasing temperature (*S-NPVer6*), so vapor pressure increases because of increasing exerted pressure on liquid surface by gas molecules (*S-VP6*), but she could not explain explicitly that kinetic energy increases with increasing temperature so that more particles has enough energy to transfer into gaseous phase by overcoming the bonds (*S-MLG6*). So conceptual understanding of P 25L was categorized as a *partial understanding* on the interview (see Table 3.5, Table 3.6, and Table 4.25).

To sum up, the results of data was presented in two subsections in this chapter. The results of Mann Whitney U test showed that there is a statistically significant difference between two groups of the high understanding of PNM and the low understanding of PNM in terms of their understanding of vapor pressure. In addition, the results derived from interviews showed the distribution of conceptual understanding of participants for specific vapor pressure concepts.

5. DISCUSSION AND CONCLUSION

The main purpose of the current study was to examine the association between first-year college students' understanding of particulate nature of matter (PNM) and their understanding of vapor pressure. In this section, the results of the research questions will be discussed. Limitations of the current study and recommendations will also be mentioned.

Conclusion 1: There was a statistically significant difference between the groups of high understanding of PNM and low understanding of PNM in terms of their understanding of vapor pressure.

The concept of vapor pressure is regarded as difficult in chemistry curriculum due to its abstract nature (Canpolat et *al*., 2006, Gopal et *al*., 2004). Azizoglu et *al*. (2006) conducted a research on vapor pressure; they found out that 15% of the undergraduate pre-service teachers held a sound understanding about equilibrium vapor pressure. In the current study, 42% of the participants, that are first-year college students, showed a scientific understanding in describing vapor pressure, and it is important to note that 30% of these participants were from the high understanding of PNM group.

Findings of the current study indicated a statistically significant difference between the groups of high understanding PNM and low understanding of PNM in terms of their understanding of vapor pressure (see Table 4.1). Although there was no special instruction offered to the participants of the study, they had already learned the topic in their General Chemistry course. Based on the given case, the participants with a high understanding of PNM had higher vapor pressure scores when compared to the participants with a low understanding of PNM. This might be depending on their prior knowledge; the participants with a high understanding of PNM were more likely to use fundamental PNM knowledge to explain the concepts associated with vapor pressure.

In the current study, the participants were expected to use their knowledge related to PNM, including phase changes, movement of particles, and intermolecular forces between particles, effectively. The participants who were capable of making connections between these concepts were also capable of answering the questions related to some vapor pressure concepts in a scientifically accepted manner.

Conclusion 2: There was not considerable difference between the levels of conceptual understanding distributions of some vapor pressure concepts across the groups of high understanding of PNM and low understanding of PNM.

The level of conceptual understanding distributions for the concepts of “evaporation”, “boiling” and “vapor pressure for a system at different temperatures” were similar for the groups of high understanding of PNM and low understanding of PNM groups.

Scientific criteria of “intermolecular forces between particles” and “movement of particles” were evaluated to determine the level of conceptual understanding for the concept of evaporation. In addition to “intermolecular forces between particles” and “movement of particles”, scientific criterion of “air pressure” also expected to be included in description of boiling concept. For comparing vapor pressure of a system at different temperatures, scientific criteria of “movement of particles”, “number of gaseous particles on liquid” and “vapor pressure” were evaluated to detect each participant’s level of conceptual understanding (see Table 3.5). As it can be seen in the results of stated concepts, there was not any considerable difference between the two groups in terms of the distribution of levels of conceptual understandings for the concepts of evaporation, boiling, and vapor pressure of a system at different temperatures (see Table 4.2, 4.5 and 4.23). It is because the participants in both groups were similar in terms of utilizing their prior knowledge of PNM related to “intermolecular forces between particles” and “movement of particles”. As it can be seen at Table 4.3 and Table 4.4, both P 6H and P 8L explained the concept of evaporation in a scientific manner by stating that intermolecular forces between particles weaken and movement ability of particles increases during evaporation. This might indicate that participants who comprehended the relationship between stated concepts of PNM were more likely to use them while explaining vapor pressure concepts.

Results also showed that participants in both groups also had similar alternative conceptions (see Table 4.3 and Table 4.4). It was identified that both P 6H and P 8L has the same alternative conception of "Heating is required for evaporation to occur" in their explanations of evaporation concept. In a similar way, it was detected that both P 2H and P 7L showed the same alternative conception of "Evaporation is a result of boiling" while they were explaining the boiling concept.

Conclusion 3: There was a considerable difference between the levels of conceptual understanding distributions of some vapor pressure concepts across the high understanding of PNM and the low understanding of PNM groups.

Based on the findings from the current study, the participants with an advanced understanding of PNM were more likely to develop a scientific understanding of vapor pressure. For the concepts of "vapor pressure", "vapor pressure in containers with different volumes", "vapor pressure for containers with different amount of liquids", "vapor pressure for different liquids in open containers" and "vapor pressure for different liquids in closed containers", there was a considerable difference between the participants' levels of conceptual understanding in favor of the high understanding of PNM group.

Most of the stated concepts above were evaluated according the scientific criteria of "equilibrium", "movement of particles", and "intermolecular forces between particles" as common. Although the participants from both groups had an idea of "movement of particles" and "intermolecular forces between particles", the "equilibrium" criterion made the difference between the high understanding of PNM and the low understanding of PNM groups.

When P 26H's explanation of vapor pressure concept was compared with P5L's explanation of vapor pressure concept (see Table 4.9 and Table 4.10), it was identified that P 26H explained vapor pressure in accordance with the scientific criteria of "equilibrium" by stating, "Equilibrium is two-sided. If we make any change on a side, a change on the other side occurs, too. We say equilibrium shifted toward forward or backward. If any change does not occur, both forward and reverse reaction continues to occur at the same rate at equilibrium." Although he couldn't make an explanation of vapor pressure including all scientific criteria, his explanation included the scientific explanation of "equilibrium". On the other hand, P5L's explanation of vapor pressure concept did not include any scientific criteria, including "equilibrium". In addition, it was detected that P 5L has an alternative conception related to "equilibrium"; that is "Equilibrium is established when the reaction is completed".

As it can be seen in Table 4.3 and Table 4.4, participants of both high understanding of PNM and low understanding of PNM groups could explain "movement of particles" and "intermolecular forces between particles" in a scientific manner. On the other hand, the task related to "vapor pressure in containers with different volumes" required including "equilibrium" concept into explanation. P 18H compared vapor pressure in containers with different volumes in a scientific manner in accordance with all scientific criteria of the task including "equilibrium" and categorized as a *scientific understanding* on the interview (see Table 4.12). But P 28L could not include "equilibrium" into the explanation of the task, he asserted that gas is compressed when the volume of vapor becomes half (see Table 4.13). The alternative conception of "Number of total vapor particles is constant regardless of external effects applied on the system when the liquid-vapor equilibrium is established" was detected in P 28L's explanations. He also could not provide a scientific explanation about the other scientific criteria due to the presence of this alternative conception related to equilibrium concept; so his understanding was categorized as *alternative conceptions* on the interview.

When the given examples above are considered, it can be concluded that the participants of high understanding of PNM group comprehended PNM concepts better; so they might have been answered the questions related to vapor pressure concepts by making connections between vapor pressure and the PNM concepts in an advanced level.

5.1. Limitations of the Study

Some limitations will be discussed in the following paragraphs. Recruiting participants from one university, selecting voluntary based sampling, and using interviews are seen as the limitations of the current study.

The main limitation of the current study was that findings cannot be extended to wider populations. Participants were recruited from one university. The students of university that the participants were recruited had high university entrance exam scores, so it can be said that it is a privileged sample. Therefore, the results of the study cannot be generalized to all first-year college students.

The second limitation was the sampling technique. Forty-eight first-year college students who were enrolled in General Chemistry I course at the same university were participated into the current study in a voluntary manner; not randomly. So the findings can be valid only for this sample.

The third limitation was that the current study used semi-structured interviews through data collection process. Interviews provided an opportunity to analyze the participants' understanding of vapor pressure for the sample deeply, but findings are still valid for the sample, it cannot be generalized.

5.2. Implications

The current study used a two-tier diagnostic test for data collection. Although there are some advantages of using multiple-choice tests, students' answers cannot be analyzed deeply; the answer may be given because of lack of knowledge, carelessness, and chance factor or error (Pesman and Eryilmaz, 2010). Two-tier tests provide more data by eliminating the disadvantages of multiple-choice tests. Teachers can easily use two-tier tests for an extensive assessment so that it helps to improve teaching and learning. Therefore, two-tier tests should be preferred to make more accurate assessments in determination of alternative conceptions and in measurement of success.

As the results of the current study showed, the high understanding of PNM group had higher level of conceptual understanding in terms of vapor pressure without any special instruction. This indicates that comprehending concepts of PNM and the relationship between them is crucial in grasping more complex concepts in chemistry. Therefore, it is highly recommended to use educational techniques like multiple representations to make these basic concepts more understandable at every level of education.

5.3. Recommendations for Further Research

Some recommendations will be discussed for the further studies in the following paragraphs.

When the limitations given in the previous paragraph is considered, study can be generalized by recruiting participants from different universities; participants with various university entrance exam scores may change the results so the further studies should be conducted with diverse samples, and participants should have various university entrance exam scores. In addition, involving participants to the further studies with random selection instead of voluntary based recruitment is recommended so that the results drawn from the data can more closely reflect the population.

Another recommendation is the extending the current study to wider populations by using surveys. Although interviews provided data on participants' conceptual understanding of vapor pressure in an in-depth manner, surveys can be helpful to obtain more data so that the findings can be more generalizable.

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APPENDIX A: PERMISSION LETTER

BOĞAZİÇİ ÜNİVERSİTESİ
İnsan Araştırmaları Kurumsal Değerlendirme Kurulu (İNAREK) Toplantı Tutanağı
2012/7

17.12.2012

Yrd. Doç. Dr. Emine Adadan,
Eğitim Fakültesi, Orta Öğretim Fen ve Matematik Alanları Eğitimi Bölümü, Boğaziçi Üniversitesi
İstanbul
0212 359 7371
emine.adadan@boun.edu.tr

Sayın Araştırmacı,

"Öğrencilerin maddenin tanecikli yapısını anlama düzeyleri ile buhar basıncı kavramlarını anlamaları arasındaki ilişkinin incelenmesi" başlıklı projeniz ile yaptığınız Boğaziçi Üniversitesi İnsan Araştırmaları Kurumsal Değerlendirme Kurulu (İNAREK) 2012/65 kayıt numaralı başvuru 17.12.2012 tarihli ve 2012/7 sayılı kurul toplantısında incelenerek etik onay verilmesi uygun bulunmuştur.

Saygılarımızla,

Prof. Dr. Hande Çağlayan (Başkan)
Moleküler Biyoloji ve Genetik Bölümü,
Fen-Edebiyat Fakültesi, Boğaziçi Üniversitesi,
İstanbul

Yrd. Doç. Dr. Özgür Kocatürk (sekreter)
Biyo-Medikal Mühendisliği Enstitüsü
Boğaziçi Üniversitesi,
İstanbul

Prof. Dr. Betül Baykan-Baykal (üye)
Nöroloji Bölümü, İstanbul Tıp Fakültesi ,
İstanbul Üniversitesi,
İstanbul

Yrd. Doç. Dr. Özlem Hesapçı (üye)
İktisadi ve İdari Bilimler Fakültesi,
İşletme Bölümü, Boğaziçi Üniversitesi,
İstanbul

Doç. Dr. Yeşim Atamer (üye)
Hukuk Fakültesi, İstanbul Bilgi Üniversitesi,
İstanbul

1

Figure A.1. Permission letter obtained from Institutional Review Board for Research with Human Subjects (İNAREK)

APPENDIX B: PARTICULATE NATURE OF MATTER – DIAGNOSTIC INSTRUMENT (PNM-DI)

MADDENİN TANECİKLİ YAPISI: DEĞERLENDİRME TESTİ

Adı - Soyadı:..

Kız ☐ Erkek ☐

Okul Adı:...

Sınıfı:..

Okul No:..

Açıklamalar

Bu test, sizlerin maddenin tanecikli yapısı ile ilgili kavramsal bilginizi ölçmek için geliştirildi.

Teste vereceğiniz cevaplar sizlerin ilgili konuyu nasıl yorumladığınızı anlayabilmemiz açısından oldukça önemlidir. Çalışma çerçevesinde elde edilecek sonuçlar değişik öğretim yöntemlerinin geliştirilmesine ışık tutacaktır.

Testte vereceğiniz cevaplar yalnızca araştırmacı tarafından incelenecek ve araştırma amaçlı kullanılacaktır. Vereceğiniz yanlış veya doğru cevaplar hiç bir şekilde ders notunuza etki etmeyecektir.

Testte toplam 14 soru mevcuttur. Her soru çoktan seçmeli iki bölümden oluşmaktadır. Birinci bölümde sorunun size göre doğru cevabını işaretlemeniz istenmektedir. Sorunun ikinci bölümünde ise, birinci bölümde seçtiğiniz cevabınızın nedenini açıklayan ifadeyi işaretlemeniz beklenmektedir.

Çalışmaya katıldığınız için çok teşekkür ederiz.

Meltem İşcan, Boğaziçi Üniversitesi

Yard. Doç. Dr. Emine Adadan, Boğaziçi Üniversitesi

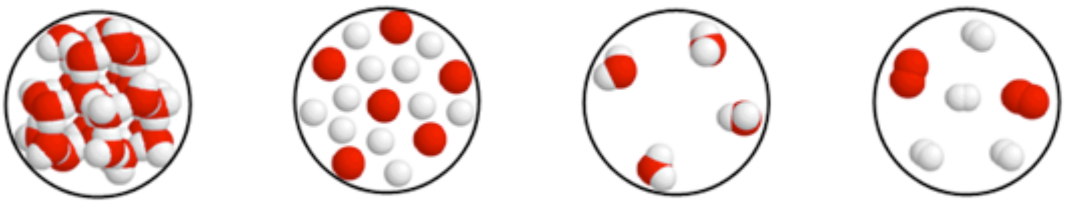
Soru 1

Bölüm A

Şekil 1 sıvı halde bulunan suyun moleküllerini temsil etmektedir.

Şekil 1

Aşağıdakilerden hangisi suyun buharlaştıktan (gaz haline geçtikten) sonraki durumunu göstermektedir?



(A) **(B)** **(C)** **(D)**

Bölüm B

Bu cevabı vermemin nedeni:

(1) Buharlaşma esnasında su molekülleri hidrojen ve oksijen atomlarına ayrışır.

(2) Buharlaşma esnasında su molekülleri arasındaki mesafe artar.

(3) Sıvı halden gaz hale geçen su molekülleri oldukça düzenli bir yapı oluşturur ve moleküller arasında boşluk bulunmaz.

(4) Buharlaşma esnasında molekül içi bağlar kırılır; su oksijen ve hidrojen gazlarına ayrışır.

(5) *Diğer neden:*……………..…………………………………………………….........

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……………………………………………………………………………………..

Soru 2

Bölüm A

Gaz fazdaki suyun bir molekülü ile sıvı fazdaki suyun bir molekülü karşılaştırıldığında; gaz fazdaki suyun bir molekülü, sıvı fazdaki suyun bir molekülünden………………….................

(A) daha küçüktür.

(B) daha hafiftir.

(C) daha büyüktür.

(D) ağırlık olarak farklı değildir, sıvı fazdaki suyun bir molekülüyle aynı ağırlıktadır.

Bölüm B

Bu cevabı vermemin nedeni:

(1) Gaz haldeki su sıvı haldeki suya göre oldukça sıkıştırılabilir yapıdadır.

(2) Su molekülü sıvı halden gaz hale geçerken küçüleceğinden, ağırlığı azalır.

(3) Sıvı haldeki su molekülü buharlaşma esnasında genleşir.

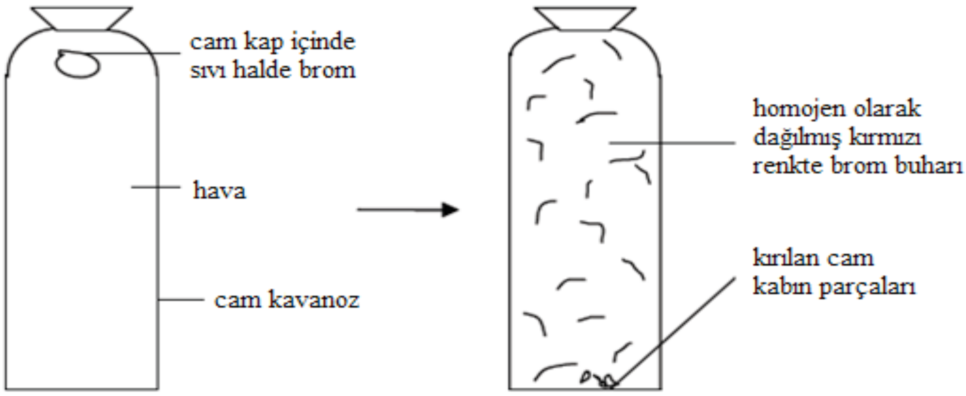
(4) Fiziksel bir değişim meydana geldiğinden dolayı molekül ağırlığında bir değişiklik olmaz.

(5) *Diğer neden*:……………………………………………………………………..........
………………………………………………………………………………………
………………………………………………………………………………………

Soru 3

Bölüm A

Zeynep içinde sıvı halde brom olan küçük bir cam kabı havayla dolu olan bir kavanozun içine atmış ve kavanozun kapağını hemen kapatmıştır. Cam kap, kavanozun dibine çarparak kırılmış ve brom buharı kap içinde yayılmaya başlamıştır. Zeynep, birkaç saat sonra, kırmızı renkli brom buharının kavanozda homojen olarak dağılmış olduğunu gözlemlemiştir.



Zeynep aynı deneyi kavanoz içerisindeki havanın büyük kısmı dışarı alındıktan sonra tekrarladığında, kırmızı renkli brom buharının birkaç saniye içinde homojen olarak dağılıp kavanozu dolduracağını gözlemlemeyi beklenmektedir. Zeynep'in bu görüşü için ne söyleyebilirsiniz?

(A) Doğru **(B)** Yanlış

Bölüm B

Bu cevabı vermemin nedeni:

(1) Daha ağır olan brom molekülleri kavanozun dibinde kalacaktır.

(2) Brom molekülleri arasında hava taneciklerinin eksikliğine bağlı olarak daha az çarpışma meydana gelecektir.

(3) Yeni durumda, brom molekülleri daha önce hava taneciklerinin yer aldığı alanda da bulunabileceklerdir.

(4) Brom molekülleri rastgele zigzag hareketlerle yavaşça kavanozu dolduracaklardır.

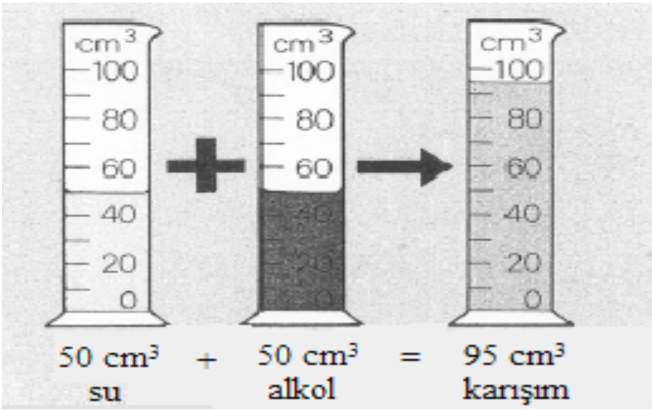
(5) Brom kavanozun içinde daha hızlı bir şekilde yayılacaktır çünkü brom ve hava tanecikleri arasında daha az çarpışma meydana gelecektir.

(6) *Diğer neden:*……………..……………………………………………………………

Soru 4

Bölüm A

Aşağıdaki şekil su ve alkol karıştırıldığında sıvının toplam hacminin azaldığını göstermektedir.



Bu bilgiye göre su ve alkol karıştırıldığında alkolün bir kısmının buharlaştığı sonucu çıkarılmaktadır. Bu görüş için ne söyleyebilirsiniz?

(A) Doğru **(B)** Yanlış

Bölüm B

Bu cevabı vermemin nedeni:

(1) Su ve alkol molekülleri birbirleri arasında kalan boş alanları doldururlar.

(2) Alkol molekülleri suyun içinde çözünür.

(3) Alkolün bir kısmı moleküller arasındaki çarpışmalardan dolayı buharlaşır.

(4) Su ve alkol molekülleri birlikte karışırlar.

(5) *Diğer neden*:……………………………………………………………………..........

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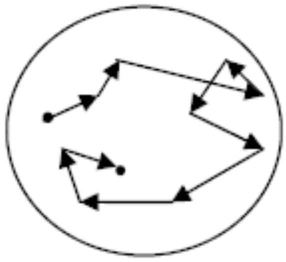
Soru 5

Bölüm A

İçerisinde hava bulunan cam bir kap içerisindeki duman mikroskop altında incelendiğinde, aşağıdaki şekilde görüldüğü gibi duman taneciklerinin rastgele zigzag hareketi (Brown hareketi) yaptığı gözlenmiştir.



Bu gözlemden hangi sonucu çıkarabilirsiniz?

(A) Duman tanecikleri havanın içinde dolaşmaktadır.

(B) Hava büyük ölçüde boşluk içermektedir.

(C) Hava rastgele hareket eden küçük taneciklerden oluşmaktadır.

(D) Duman tanecikleri hava taneciklerinden daha büyüktür.

Bölüm B

Bu cevabı vermemin nedeni:

(1) Duman tanecikleri büyüktür.

(2) Duman tanecikleri arasında geniş boşluklar vardır.

(3) Çarpışan duman tanecikleri rastgele zigzag bir şekilde hareket eder.

(4) Hava tanecikleri sürekli olarak duman tanecikleriyle çarpışmaktadır.

(5) *Diğer neden*:……………………………………………………………..………..........

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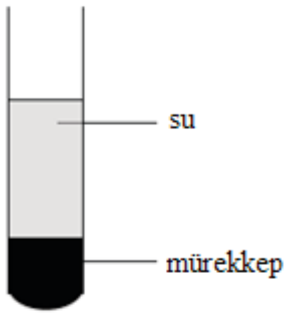
Soru 6

Bölüm A

Aşağıdaki şekilde içinde su bulunan ve dibine az miktarda mavi mürekkep konulmuş bir test tüp gösterilmiştir.



ayrı mürekkep ve su katmanları içeren test tüpü

Bir kaç saat sonra mürekkebin homojen mavi bir çözelti oluşturacak şekilde suyun içinde yayılması beklenmektedir. Bu görüş için ne söyleyebilirsiniz?

(A) Doğru **(B)** Yanlış

Bölüm B

Bu cevabı vermemin nedeni:

(1) Mürekkep tanecikleri suyun içinde kolayca çözünür.

(2) Daha ağır olan mürekkep tanecikleri test tüpün dibine çöker.

(3) Mürekkep tanecikleri sürekli gelişigüzel bir şekilde hareket etmektedirler.

(4) Mürekkep ve su tanecikleri karışmazlar.

(5) *Diğer neden*:…………………………………………………………………...........

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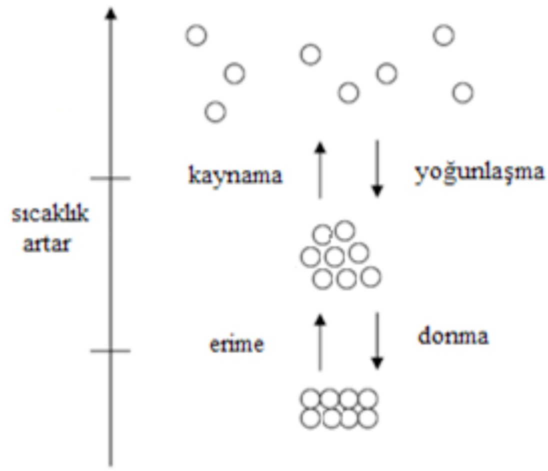
<u>Soru 7</u>

Bölüm A

Aşağıdaki şekilde maddenin farklı hallerinde su taneciklerinin dizilimi gösterilmektedir.



Hangi hal değişimlerinde madde ısı enerjisi almaktadır?

(A) katı ➔ sıvı ➔ gaz

(B) gaz ➔ sıvı ➔ katı

Bölüm B

Bu cevabı vermemin nedeni:

(1) Su molekülleri birbirinden uzaklaşır.

(2) Su molekülleri içindeki bağlar kırılır.

(3) Su molekülleri arasındaki çekim kuvvetleri zayıflar.

(4) *Diğer neden*:……….....…………………………………………………………........

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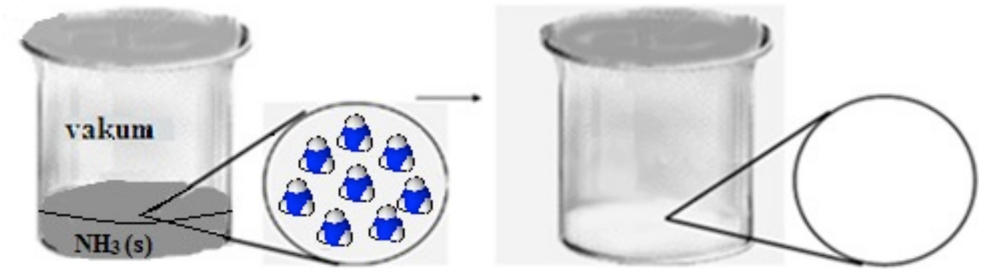
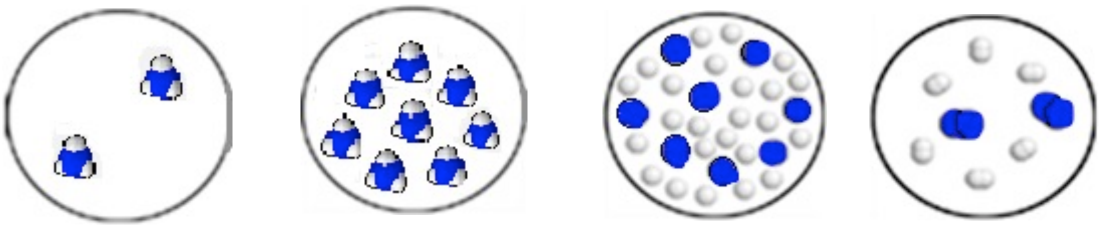
Soru 8

Bölüm A

Bir miktar sıvı amonyak [-NH_3(s)-] aşağıdaki şekilde görüldüğü gibi kapalı bir kapta tamamen buharlaştırılmıştır (gaz haline getirilmiştir):



Aşağıdaki gösterimlerden hangisi kapalı kaptaki sıvı amonyak tamamen buharlaştıktan sonraki durumu temsil etmektedir?



(A) **(B)** **(C)** **(D)**

Bölüm B

Bu cevabı vermemin nedeni:

(1) Sıvı haldeki amonyak tamamen buharlaştırıldığında amonyak molekülleri arasındaki mesafe artar.

(2) Fiziksel değişim gerçekleştiği için herhangi bir değişiklik olmaz.

(3) Amonyak molekülleri buharlaşma esnasında atomlarına ayrışır.

(4) Buharlaşma esnasında molekül içi bağlar kırılır; amonyak nitrojen (N_2)ve hidrojen (H_2) gazlarına ayrışır.

(5) *Diğer neden*:……….....…………………………………………………………..........

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<u>Soru 9</u>

Bölüm A

Gaz fazındaki su moleküllerine ısı verildiğinde..

(A) daha büyük olurlar

(B) daha hızlı hareket ederler

(C) daha hafif olurlar

(D) sıvı hale geçerler

Bölüm B

Bu cevabı vermemin nedeni:

(1) Su molekülleri sıcaklık arttığı için genleşir.

(2) Gaz haldeki su moleküllerinin ağırlığı yoktur.

(3) Gaz haldeki su molekülleri ısıtıldığında yükselir.

(4) Su moleküllerine ısı verildiğinde kinetik enerjisi artar.

(5) *Diğer neden:*……………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

Soru 10

Bölüm A

Su buharlaşarak sıvı halden gaz hale geçerken, enerji ………….........… gereklidir.

(A) atomlar arasında yeni bağlar oluşturmak için

(B) molekülün içindeki oksijen ve hidrojen atomları arasındaki bağları kırmak için

(C) su moleküllerini diğer su moleküllerinden uzaklaştırmak için

(D) moleküller arasında yeni bağlar oluşturmak için

Bölüm B

Bu cevabı vermemin nedeni:

(1) Bağlar enerji depolar.

(2) Enerji oksijen ve hidrojen atomlarının daha hızlı hareket etmesini sağlar.

(3) Enerji su moleküllerinin daha hızlı hareket etmesini sağlar.

(4) Enerji su moleküllerinin genleşmesini sağlar.

(5) *Diğer neden:*……………………………………………………………………..

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Soru 11

Bölüm A

Bir kapta su kaynarken sudan kabarcıklar çıktığını görürüz. Bu kabarcıkların içinde ne vardır?

(A) ısı

(B) hava

(C) oksijen ve hidrojen gazı

(D) su buharı

Bölüm B

Bu cevabı vermemin nedeni:

(1) Isıtıcıdan gelen ısı kabarcıklar yoluyla havaya taşınır.

(2) Su içinde hava vardır ve kaynama sırasında hava baloncukları ortaya çıkar.

(3) Su gaz haline geçtiğinde hidrojen ve oksijen gazlarına ayrışır.

(4) Su gaz haline geçtiğinde su molekülleri arasındaki mesafe artar.

(5) *Diğer neden*:………....…………………………………………………………........

…………………………………………………………………………………………

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Soru 12

Bölüm A

Sıvı fazdaki suyun molekülleri, su buharlaştığında ....

(A) daha büyük olurlar

(B) daha hafif olurlar

(C) daha hızlı hareket ederler

(D) şekil değiştirirler

Bölüm B

Bu cevabı vermemin nedeni:

(1) Su molekülleri sıcaklık arttığı için genleşir.

(2) Sıvı fazdaki su buharlaştığında moleküllerin kinetik enerjisi artar.

(3) Katı haldeyken molekülleri küp şeklinde bulunurken, gaz halde ise molekülleri düzgün yuvarlaklar şeklindedir.

(4) Gaz fazdaki su sıvı fazdaki haline göre daha az tanecik bulundurmaktadır.

(5) *Diğer neden:*………………………………………………………………….....
………………………………………………………………………………………
………………………………………………………………………………………

<u>Soru 13</u>

Bölüm A

Suyun $0^{o}C$'de katı, $24^{o}C$'de sıvı ve $100^{o}C$'de gaz fazda olduğu düşünüldüğünde, sıvı fazdaki suyun molekülleri ile gaz fazdaki suyun molekülleri karşılaştırıldığında ....

(A) sıvı fazdaki suyun molekülleri daha hızlı hareket etmektedir

(B) sıvı fazdaki suyun molekülleri daha yavaş hareket etmektedir

(C) aynı hızda hareket etmektedir

(D) sıvı fazdaki suyun molekülleri daha gelişigüzel hareket etmektedir

Bölüm B

Bu cevabı vermemin nedeni:

(1) Sıvı fazdaki moleküllerin kinetik enerjisi daha fazladır.

(2) Gaz fazdaki moleküllerin kinetik enerjisi daha fazladır.

(3) Aynı madde olduğundan kinetik enerjisi aynıdır.

(4) Sıvı haldeki moleküller gaz haldeki moleküllere göre çok daha az yer kaplamaktadır.

(5) *Diğer neden:*…………………………………………………………………........

………………………………………………………………………………………

………………………………………………………………………………………

Soru 14

Bölüm A

Ocağın üzerine yerleştirilen beherin içerisinde bulunan su kaynamaya başlamıştır. Kaynama sırasında beherin ağzı cam bir kapakla kapatıldığında kapağın iç tarafında su damlacıklarının gözlenmesi beklenmektedir. Bu görüş için ne söyleyebilirsiniz?

(A) Doğru **(B)** Yanlış

Bölüm B

Bu cevabı vermemin nedeni:

(1) Buhar soğumakta ve su molekülleri birbirlerine yaklaşarak bir araya gelmektedir.

(2) Hidrojen ve oksijen gazları birleşerek suyu oluşturmaktadır.

(3) Buhar havayla birleşerek kapağın iç tarafını ıslatmaktadır.

(4) Kapak iyi kapatılmadığından dışarıdan su girmektedir.

(5) *Diğer neden:*……………………………………………………………..........................

………………………………………………………………………………………

………………………………………………………………………………………

APPENDIX C: INTERVIEW PROTOCOL

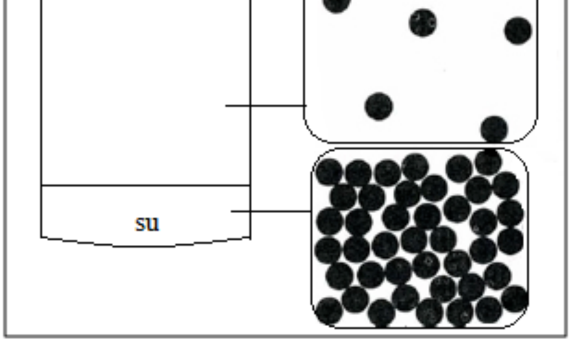
I. BÖLÜM - Kavramlar

1. Buharlaşma nedir?
   a. Buharlaşma esnasında moleküler seviyede neler olduğunu açıklar mısın?
2. Kaynama nedir?
   a. Kaynama esnasında moleküler seviyede neler olduğunu açıklar mısın?
3. Buhar basıncı nedir?
   a. Buhar basıncının moleküler seviyede ne anlama geldiğini açıklar mısın?

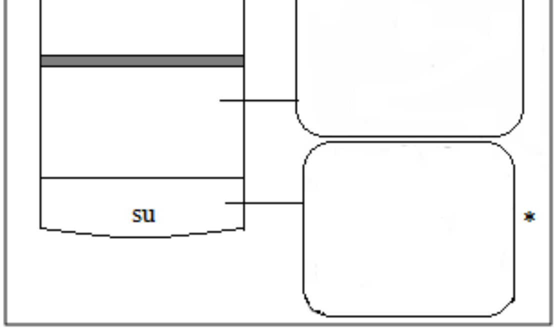
II. BÖLÜM – Hacmi Değişen Kapalı Kap İçin Buhar Basıncı Karşılaştırması

1. Şekil A'da gösterildiği gibi kapalı bir kapta bir miktar su bulunmaktadır ve 25^{o}C'de sıvı-buhar dengesi sağlanmıştır. Şekil A'daki kabın hacmi, Şekil B'de gösterildiği gibi buharın bulunduğu kısmın hacmi yarıya inecek şekilde değiştirilmiştir.
   a. Su ve buharın bulunduğu kısımların birim hacimlerini moleküler seviyede inceleyebilseydiniz ne göreceğinizi Şekil B'de işaretli (*) alanlara çizerek çizimini açıklar mısın?
   b. Kabın hacmi içindeki buharın hacmi yarıya düşecek şekilde değiştiğinde, buhar basıncı nasıl değişir?
   c. Cevabını moleküler seviyede açıklar mısın?

Şekil A



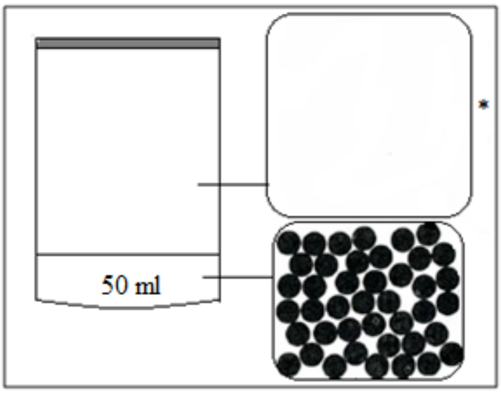
Şekil B



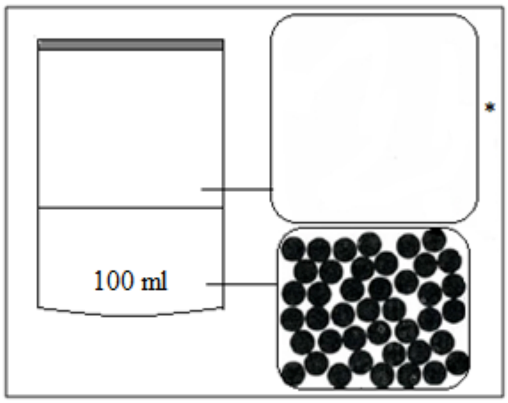
III. BÖLÜM – Farklı Miktarlarda Sıvı Bulunduran Kapalı Kaplar İçin Buhar Basıncı Karşılaştırması

1. Şekil I ve Şekil II'de görüldüğü gibi, eşit hacimli kapalı kaplar içerisinde farklı hacimlerde su bulunmaktadır ve 25^{o}C'de her birinin sıvı-buhar dengesi sağlanmıştır.
    a. Her iki sistem için buharın bulunduğu kısımlarda birim hacimleri moleküler seviyede inceleyebilseydiniz ne göreceğinizi işaretli (*) alanlara çizerek çizimini açıklar mısın?
    b. İki sistemin buhar basınçlarını karşılaştırır mısın?
    c. Cevabını moleküler seviyede açıklar mısın?

Şekil I

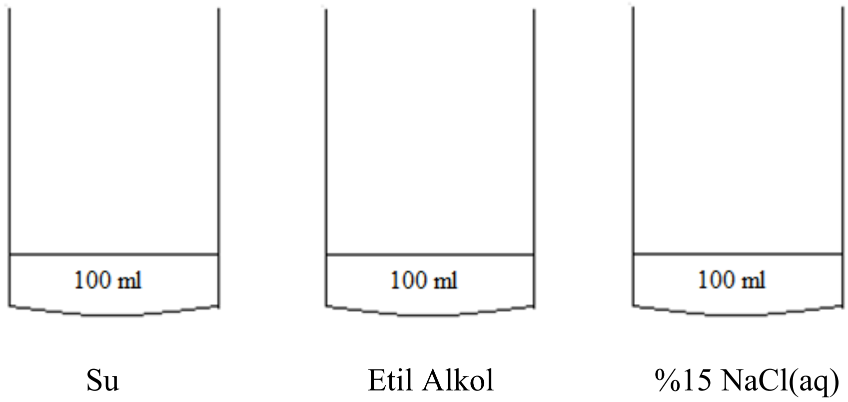


Şekil II

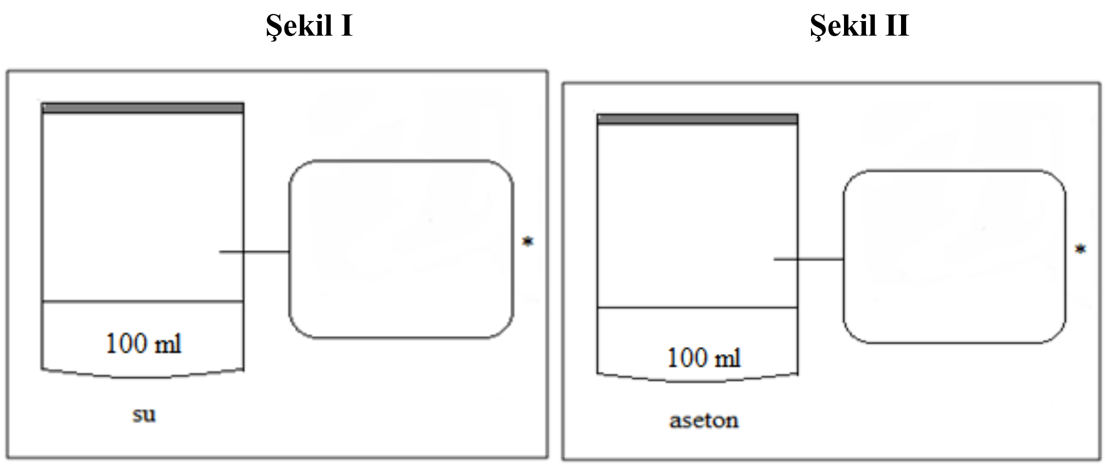


IV. BÖLÜM – Farklı Sıvılar Bulunduran Sistemler İçin Buhar Basıncı Karşılaştırması

1. Ağzı açık kaplarda, eşit hacimde su, etil alkol ve %15 NaCl (aq) içeren üç sistemin kaynama esnasında buhar basınçlarını karşılaştırır mısın?
   a. Neden bu sıralamayı yaptığını moleküler seviyede açıklar mısın?

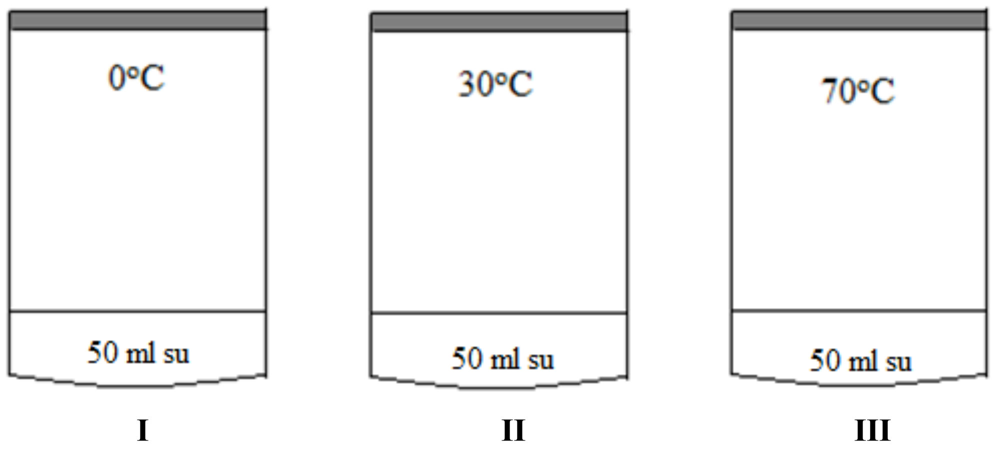


2. Şekil I ve Şekil II'de görüldüğü gibi, eşit hacimli kapalı kaplar içerisinde eşit miktarlarda su ve aseton bulunmaktadır ve 25^{o}C'de herbirinin sıvı-buhar dengesi sağlanmıştır.
   a. Her iki sistem için buharın bulunduğu kısımların birim hacimlerini moleküler seviyede inceleyebilseydin ne göreceğinizi işaretli (*) alanlara çizerek çizimini açıklar mısın?
   b. İki sistemin buhar basınçlarını karşılaştırır mısın?
   c. Cevabını moleküler seviyede açıklar mısın?



V. BÖLÜM – Farklı Sıcaklıklarda Sıvı Bulunduran Sistemler İçin Buhar Basıncı Karşılaştırması

1. Eşit hacimde 0^oC, 30^oC ve 70^oC'de su içeren üç özdeş kapalı kap için suyun buhar basınçlarını karşılaştırır mısın?
   a. Neden bu sıralamayı yaptığını moleküler seviyede açıklar mısın?



ANSWER KEY

Soru 1

Aşağıda verilen kavramları kendi kelimelerinizle tanımlayarak açıklayınız.

(a) Buharlaşma: Sıvıyı oluşturan tanecikler katılara oranla birbirlerine daha uzak ve yapılarını oluşturan tanecikler arasındaki çekim kuvvetleri daha zayıftır. Sıvıları buharlaştırmak (gaz hale getirmek) için tanecikleri arasındaki çekim kuvvetlerini yenmek amacıyla enerji vermek gerekir. Yeterli enerji verildiğinde tanecikler sıvı yüzeyinden kurtularak gaz hale geçerler. Bu olaya buharlaşma denir (MEB). Sıvı bir maddenin ısı alarak gaz haline geçmesi olayına buharlaşma denir. Buharlaşma olayı sıvı yüzeyinde olur. Isı alan sıvı moleküllerinden bazıları sıvı yüzeyinde gaz haline geçer. Buharlaşmaya basınç ve diğer fiziksel şartların etkisi çoktur. Buharlaşma her sıcaklıkta olabilir. Maddeler dışarıdan ısı alarak buharlaşırlar. Dolayısıyla buharlaşmanın olduğu yerde serinleme olur. Sıcaklığın artması buharlaşmayı hızlandırır. Açık hava basıncının azalması buharlaşmayı artırır. Sıvının açık yüzey alanı arttıkça buharlaşma daha fazla olur.

(b) Kaynama: Sıvının buhar basıncının dış basınca eşit olduğunda, sıvı içinde oluşan hızlı buharlaşma, sıvı taneciklerinin gaz haline geçmesi ve sıvıyı terk etmesidir, sıvının her yerinde buharlaşma. Saf maddelerin kaynama noktası sabittir. Kaynama süresi boyunca sıcaklık değişmez. Sıvı bir maddenin içinde bir madde çözünmüşse karışımın kaynama noktası yükselir. Çözünen madde miktarı arttıkça kaynama noktası yükselir. Aynı ortamda bütün sıvıların kaynama anındaki buhar basınçları eşittir. Maddenin cinsine, saflığına ve ortamın basıncına bağlıdır.

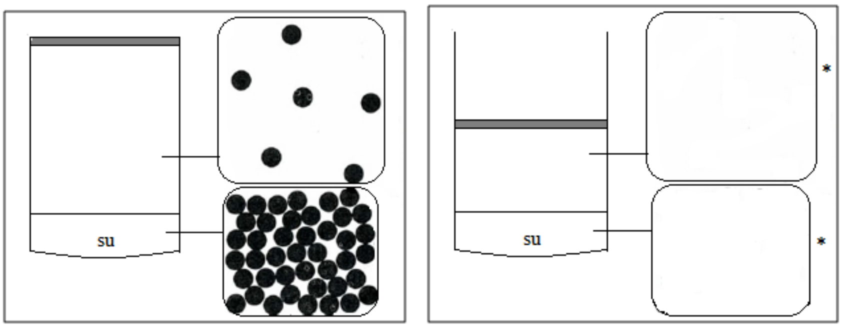
(c) Buhar basıncı:
Belli sıcaklıkta, sıvı ya da katı haliyle dengede bulunan buharın gösterdiği basınç (MEB). Buharlaşan her maddenin belli bir sıcaklık için buhar basıncı o maddenin ayırt edici bir özelliğidir. Sıcaklık arttıkça buharlaşma da artacağı için o maddenin de yüzeyindeki buhar basıncı artar. Bir sıvının buhar basıncı dış ortamdaki gaz basıncından yüksek olamaz. Bir sıvının buhar basıncı ancak kaynama noktasına geldiği zaman atmosfer basıncına eşit olur.

Soru 2

Bölüm A

Şekil A'da gösterildiği gibi kapalı bir kapta bir miktar su bulunmaktadır ve 25^{o}C'de sıvı-buhar dengesi sağlanmıştır. Şekil A'daki kabın hacmi, Şekil B'de gösterildiği gibi buharın bulunduğu kısmın hacmi yarıya inecek şekilde değiştirilmiştir. Su ve buharın bulunduğu kısımların birim hacimlerini moleküler seviyede inceleyebilseydiniz ne göreceğinizi Şekil B'de işaretli (*) alanlara çizerek gösteriniz.

Figure I **Figure II**



Bölüm B

Yukarıdaki şekillerde gösterildiği gibi kabın hacmi içindeki buharın hacmi yarıya düşecek şekilde değiştiğinde, buhar basıncının nasıl değişeceğini **moleküler seviyede açıklayınız.**

Sabit sıcaklıkta, buhar basıncı sıvısıyla dengede olduğu ortamda buharın hacminin değiştirilmesiyle değişmez. Buhar basıncı sıcaklığa, maddenin cinsine, maddenin saflığına bağlıdır, dış basınca bağlı değildir. Buhar basıncı maddenin ayırt edici bir özelliğidir. Aynı şartlarda bulunan maddeye dışarıdan yapılan etkiyle buhar basıncında değişim olmaz. Maddenin sıvı ve buhar halleri arasında denge durumu, buhar halinde moleküllerin bir kısmının sıvı hale geçmesiyle tekrar kurularak devam eder.

Sıvı kısımda moleküller öteleme ve titreşim hareketi yapmaya devam edeceklerdir, bir değişiklik olmayacaktır. Sıvının üst tarafında kalan hacimde bulunan buhar molekülü sayısında azalma olacaktır, birim hacimde aynı sayıda buhar molekülü olacaktır.

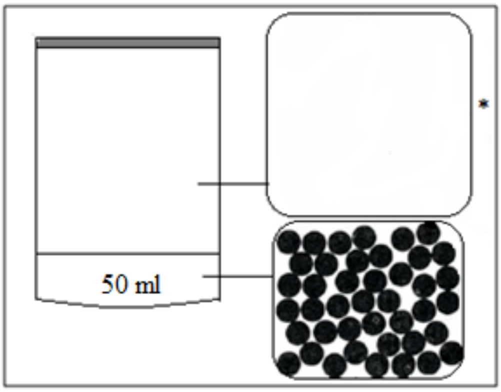
<u>Soru 3</u>

Bölüm A

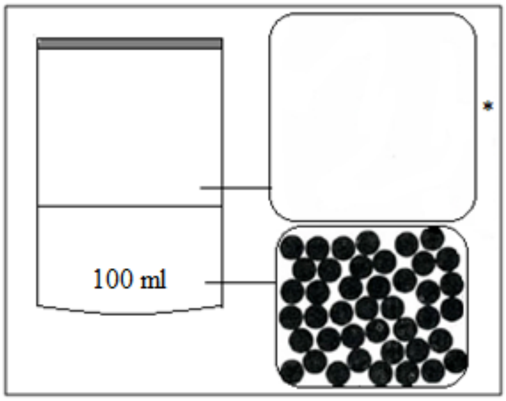
Aşağıda Şekil I ve Şekil II'de görüldüğü gibi, eşit hacimli kapalı kaplar içerisinde farklı miktarlarda su bulunmaktadır ve 25°C'de herbirinin sıvı-buhar dengesi sağlanmıştır.

Her iki sistem için buharın bulunduğu kısımlarda birim hacimleri moleküler seviyede inceleyebilseydiniz ne göreceğinizi işaretli (*) alanlara çizerek gösteriniz.

Şekil I



Şekil II



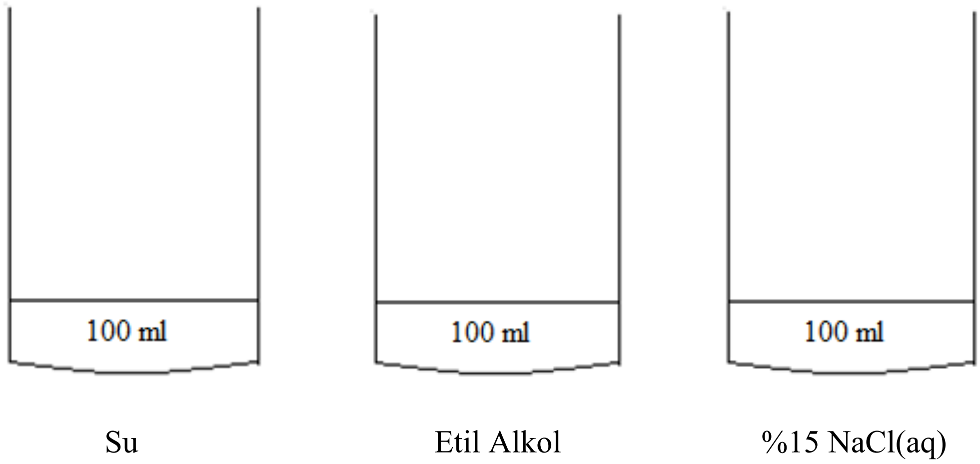
Bölüm B

İki sistemin buhar basınçlarını karşılaştırınız. **Cevabınızı moleküler seviyede açıklayınız.**

İki sistemin buhar basınçları madde miktarından bağımsız olarak aynıdır. Aynı madde aynı şartlarda bulunmaktadır.

50 ml su bulunan kapta toplamda daha fazla sayıda buhar molekülü bulunacaktır, böylece 100 ml su bulunan kapta olan buhar moleküllerinin yaptığı basınca eşit basınç uygulayacaklardır. Birim hacimde ise aynı sayıda buhar molekülü gözlenecektir.

Soru 4



Yukarıda ağzı açık kaplarda, eşit hacimde farklı sıvılar içeren üç sistem gösterilmektedir. Bu sistemlerin kaynama esnasında buhar basınçlarını karşılaştırınız. **Cevabınızı moleküler seviyede açıklayınız.**

Kaynama esnasında tüm sistemlerin buhar basınçları dış basınca, dolayısıyla birbirlerine eşittir. Kaynama esnasında sıvının her noktasında buharlaşma olmaktadır. Moleküller gaz faza geçebilmek için yeterli kinetik enerjiye sahip olmuşlardır. Moleküllerin kinetik enerjileri moleküller arası kuvvetleri yenip gaz faza geçebilmelerini sağlar ve bu esnada sitemin buhar basıncı dış basınca eşittir.

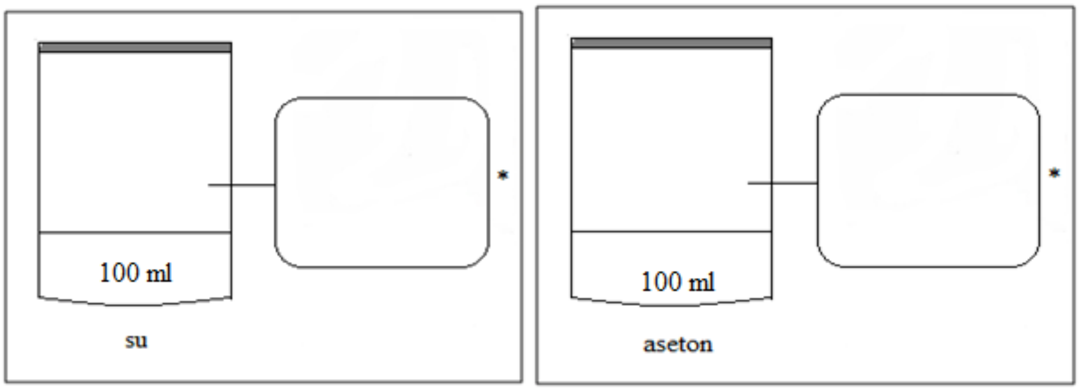
Soru 5

Bölüm A

Aşağıda Şekil I ve Şekil II'de görüldüğü gibi, eşit hacimli kapalı kaplar içerisinde eşit miktarlarda su ve aseton bulunmaktadır ve 25^{o}C'de herbirinin sıvı-buhar dengesi sağlanmıştır.

Her iki sistem için buharın bulunduğu kısımların birim hacimlerini moleküler seviyede inceleyebilseydiniz ne göreceğinizi işaretli (*) alanlara çizerek gösteriniz.

Şekil I **Şekil II**



Bölüm B

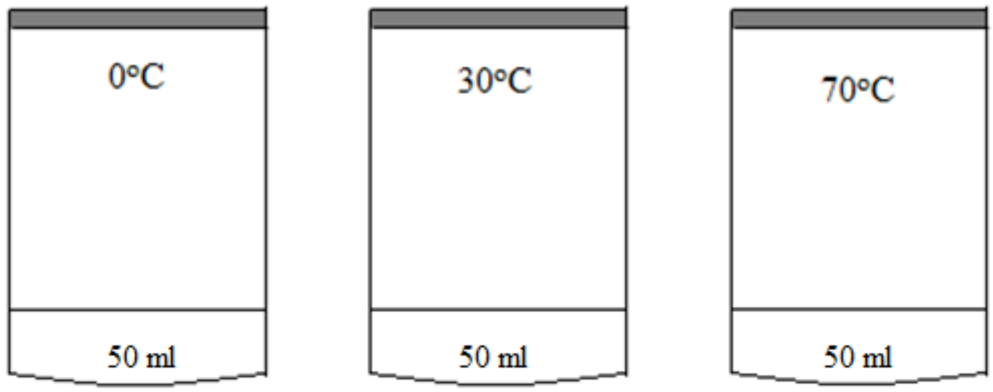
İki sistemin buhar basınçlarını karşılaştırınız. **Cevabınızı moleküler seviyede açıklayınız.**

Şekil II'deki sistemin buhar basıncı daha yüksektir ve birim hacimde daha fazla buhar molekülü gözlenecektir. Buhar basınçlarının farklı olması su ve asetonun molekül yapılarının farklı olmasından kaynaklanmaktadır. Aseton bir ketondur, molekül ağırlığı sudan fazladır ve moleküller arası kuvvet daha zayıftır. Bu nedenle kaynama noktası daha düşüktür ve aynı sıcaklıkta buhar basıncı sudan daha yüksektir.

<u>Soru 6</u>

Bölüm A

Aşağıdaki şekilde eşit hacimde su içeren üç özdeş kapalı kap gösterilmektedir. Her kapta bulunan su farklı bir sıcaklıktadır.



I **II** **III**

Bölüm B

Farklı sıcaklıklardaki bu sıvıların buhar basınçlarını karşılaştırınız. **Cevabınızı moleküler seviyede açıklayınız.**

III > II > I şeklindedir.

Sıcaklık arttıkça taneciklerin kinetik enerjisi artar, böylece daha fazla molekül sıvı fazdan gaz faza geçebilmek için yeterli enerjiye sahip olur ve dolayısıyla basınç da artar. Bu nedenle Şekil III'teki sistemin buhar basıncı en yüksektir.